OASIS FINANCIAL MODULE

Authors: Peter Taylor, Johanna Carter – Oasis Loss Modelling Framework Ltd.

This document sets out the methods and options for calculating ground-up losses, and the way insurance policy terms and conditions are applied in the "Oasis Financial Module". This is the principal function of the Oasis "Kernel". The Oasis "Kernel" additionally includes the management of technical processes for webservices, generation of instructions to execute data inputs, the "Financial Module" calculations, and outputs.

The Oasis Loss Modelling Framework uses a philosophy for loss calculations which reflects its origins within the insurance industry. This philosophy differs considerably from approaches found in most other catastrophe loss modelling software, so consideration is given to comparing and contrasting Oasis with the popular methods and why it is to be expected that Oasis will express uncertainty more adequately. There will be many cases where the differences in methodology may not be material, but there will be plenty where it is, especially when it comes to quantifying uncertainties and the effect these uncertainties have on price and capital.

WHY THIS MATTERS

Perhaps the most important reason for reading this paper is help everyone see how catastrophe loss models calculate their numbers. Whilst there are client-confidential analyses of "financial modules" by the main providers, they are not published openly nor, to our knowledge, has there been any critique of their inadequacies.

Financial calculations only matter if they make a difference in pricing, allocating capital, or managing a business. Oasis's Financial Module is a high fidelity tool that portrays a richer insight into risk as well as showing up the errors inherent in simplifications in common use.

By providing both a conceptual framework and set of practical tools, users, management and regulators can challenge vendor modelling companies and help them raise their game.

BACKGROUND

The Oasis Loss Modelling Framework (LMF) is a way of dividing up the elements of catastrophe loss modelling into "plug and play" components as shown in Figure 1. Oasis isn't a model or a front-end for users or an output analysis tool. It is instead a calculator that can be communicated with using webservices. The central part, shown in black, is termed the "Kernel" as it sits agnostically behind "plug and play sockets" or connectors that relate the

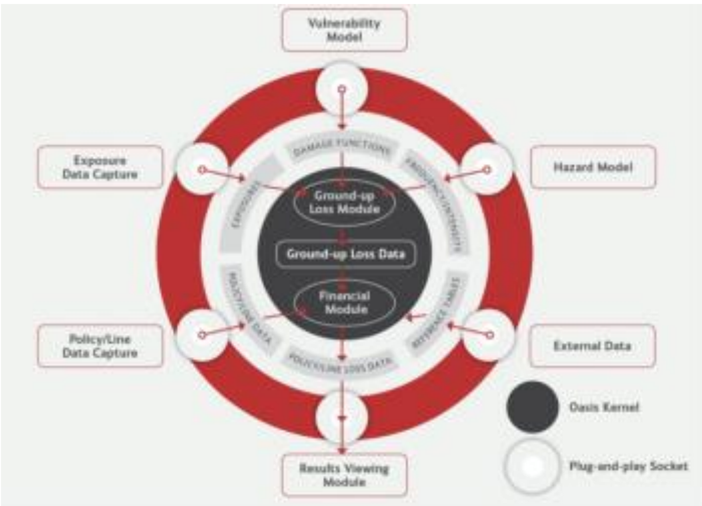


Figure 1 – The Oasis Loss Modelling Framework

external actualised model and business data to the abstract structures used for the calculations.

The Oasis LMF is a "framework" in that it provides structures within which particular solutions can be developed to solve particular problems. The "plug-and-play" connections to models and user input and outputs are one of the elements of generality in the LMF; the other is the way that financial calculations are done. In designing the methods and options for the calculation, four considerations were incorporated:

- **Non-parametric probability distributions**. Modelled and empirical intensities and damage responses can show significant uncertainty, sometimes multi-modal (that is there can be different peaks of behaviour rather than just a single central behaviour). Moreover, the definition of the source insured interest (e.g. property) location and characteristics (such as occupancy and construction) can be imprecise. The associated values for event intensities and consequential damages can therefore be varied and their uncertainty can be represented in general as probability distributions rather than point values[1]. The design of Oasis therefore makes no assumptions about the probability distributions and instead treats all probability distributions as probability masses in discrete bins, including using closed interval point bins such as the values [0,0] for no damage and [1,1] for total damage. Thus Oasis uses histograms (also termed "discrete" or "binned") probability distributions. How this is done is described below.
- **Monte-Carlo sampling**. Insurance practitioners are used to dealing with losses arising from events. These losses are numbers, not distributions, and policy terms are applied to the losses individually and then aggregated and further conditions or reinsurances applied. Oasis takes the same perspective, which is to generate individual losses from the probability distributions and the way to achieve this is random sampling called "Monte-Carlo" sampling from the use of random numbers (as if from a roulette wheel) to solve equations that are otherwise intractable.
- **Correlation of intensity and of damage across coverages and locations**. Correlations are typically modelled between coverages and between locations. Let's take these in turn. For coverages at a single location, the question is whether damage between, say, buildings and contents, is correlated. Models often just fully correlate in the sense of using the same random numbers to sample the distributions for coverages at a property. A more sophisticated way is to use a regression correlation coefficient and generate random numbers using pairwise correlation coefficients. These coefficients are often relatively easy to estimate from claims data and the degree of correlation expressed in terms of a correlation coefficient. Another way to handle the correlation of damage could be to take a primary distribution (such as buildings) and sample that and then apply a correlation matrix for the damage to another coverage given the sampled damage from the primary distribution. This does not require separate

[1] Having said that, Oasis works with many models some of which are purely point estimates (mean) of intensity. Some models use parametric ("closed-form") continuous distributions, and some use histogram binned distributions. Many use a combination of continuous and point (Dirac delta function) probability distributions.

sampling of the related distributions. It is mathematically equivalent to correlated sampling. Another route is to extend the conditional calculation by allowing a probability distribution (not just a value) to depend on the primary distribution. Business interruption, for example, can be modelled as a probability distribution conditional on property (buildings and contents damage).

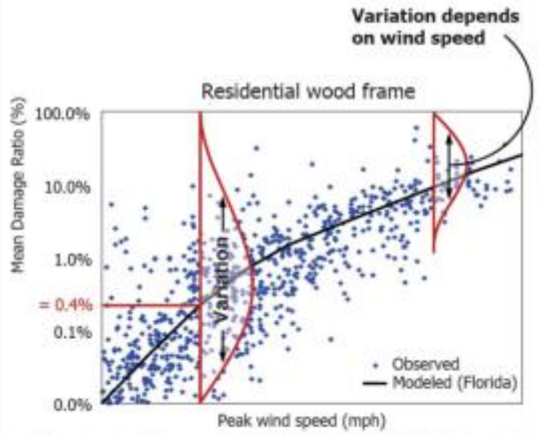
For locations, the most obvious correlation is likely to be that variations in intensity are likely to be lower for adjacent properties and independent if they are far apart. It is also arguable that vulnerability (leading to damage) might be correlated locally if, say, systemic variations in building practice occurred in a location due to the same builder. These two are intensity correlation and vulnerability correlation. It is even conceivable that the combination of intensity and vulnerability might be related as with a failure of flood defences in which case intensity and vulnerability are correlated. A complex matter, to be sure, but of potentially large financial consequence. Oasis supports all these variations one way or another as described in APPENDIX D, but the onus falls increasingly on the model provider and the use of APIs where location correlations are concerned.

- **Data-driven Application of Insurance Terms and Conditions**. As well as the agnostic approach to ground-up losses, Oasis LMF also uses its agnostic approach for policy terms and conditions. Whether insurance or reinsurance the variations and complexities are endless. For insurance, though, they fall into three types of process – iterative aggregation to a "level", application of rules to determine the element of loss that is insured, and then back-allocation to lower levels for processing to the next "level". Reinsurance is more complicated as there can be inuring policies from which a particular reinsurance benefits – and not just simple inuring policies, in actual fact there are often very complex reinsurance programme structures. The modelling of these complex cases is not intended to be covered in Release 1 of Oasis, though simple event-based inurings and many layered facultative reinsurances can be handled. Application of Oasis to complex reinsurance programmes will be covered in Release 2, but they are described below in brief anyhow.

ALTERNATIVE APPROACHES

The methods chosen by Oasis are general and cover most cases known in other financial modelling methods (albeit using discrete numeric calculations in place of closed-form continuous functions). However, quite different methods are commonly used today in other vendor and internally developed modelling software so it is worth explaining these and commenting on the differences that might follow if using them compared to Oasis LMF methods.

- **Source probability distributions for intensity and damage.** There are many ways in which different models represent event footprint intensity and associated damage. Some just provide mean values (simply mean damage models); others provide full probability distributions for both intensity and vulnerability. Many use point values for intensity coupled with damage (vulnerability) distributions. Most use parametric distributions for damage. For example, a popular catastrophe loss model uses one of beta, gamma, or beta-Bernoulli depending on the peril; others such as flood models use uniform distributions for flood intensity and truncated normal for damage; earthquake models popularly use truncated lognormal for intensity and beta for damage. A few allow fully histogramic distributions, especially for vulnerability. There are sometimes peculiar, and arguably erroneous, reasons behind these choices and significant differences in the losses they calculate. Taking damage/vulnerability functions in particular, the convention is to use plots of mean damage ratios by intensity and then calculate the mean and standard deviation and fit distributions to these moments (e.g. beta distribution). See Figure 2. The flaw with this method is that these are plots of <u>mean</u> damage ratios not actual damage ratios. Individual properties will therefore respond differently, especially for chances of no damage and total loss which get "washed out" with mean damage ratios.



Jean-Sébastien Lagacé, Catastrophe Modeling, March 28th 2008 – Université Laval

Figure 2 - Plots of Mean Damage Ratios

Parameterised distributions are typically smooth and uni-modal so do not reflect variations in damage outcomes due to substructures or incomplete classifications (e.g. occupancy might involve many construction types; "unknown" would almost certainly mean a complex multi-modal distribution). In short, using solely parametric distributions is the triumph of hope over experience.

Yet that is what is typically done and means outputs look disarmingly smooth and regular with nice central tendency as one is led to believe from school statistics. This is only likely to be valid where the Central Limit Theorem for a large number of independent identically distributed random variables (properties in this case) leads to a normal central tendency. Otherwise, the loss distribution information which could be vital for excess

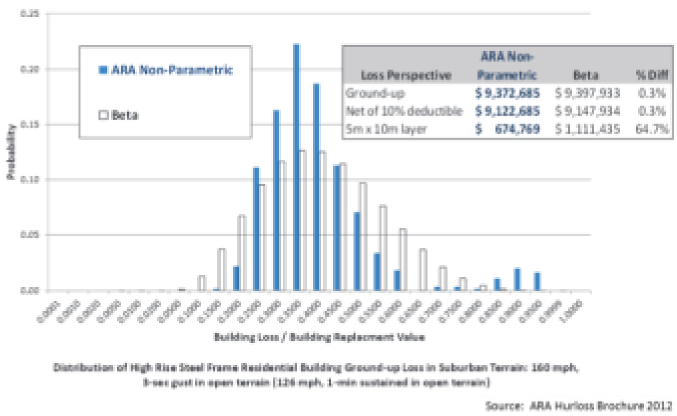


Figure 3 - ARA's Non-parametric Event Loss distribution

of loss calculations gets washed out before the policy terms can be applied. The companies using recognised uncertainty in the source distributions will be better equipped to understand the likelihood of loss, price and capital needs of the full loss distributions giving them an arbitrage advantage. One model that does use full vulnerability distributions is Applied Research Associates (ARA) in their HurLoss model. The diagram from their sales brochure shown in Figure 3 illustrates the advantage of better information: the true bi-modal distribution results in a significantly different price for an excess layer versus its smooth, parameterized counterpart.

- **Calculation of losses.** The alternatives are to compute out all possible probability combinations and then combine them (sometimes termed "convolution") or to pick some metrics, such as a mean and standard deviation, and calculate these using numerical integration and then assume some closed form distribution. Further terms and conditions would then be applied to the closed form distribution. For example, the incomplete beta distribution for deductibles and limits if the beta distribution had been chosen for the closed form distribution of ground-up losses by event. It only takes a little reflection to see that following through sampled losses as if they were actual losses is closer to what happens, more versatile, and more accurate for the many complex terms and conditions that apply in insurance. The downsides are that it is computationally intensive and the numbers are statistical not numerically integrated so an important factor is taking sufficient samples relative to a desired precision of calculation. Oasis has written a paper on this question - "Sampling Strategies and Convergence", available on the Oasis website. Whether the full uncertainty approach of Oasis will make any difference to numbers affecting underwriting depends on the problem and the metrics of interest. This is especially relevant whenever there are excess of loss conditions as the assumptions of closed form (e.g. beta) distributions of event losses can be sensitive to the model. As a general rule, large numbers of homogenous properties (e.g. residential treaties) will give convergent answers so uncertainty may not matter as much, whereas for commercial property the uncertainty is very likely to affect the results. This is exemplified in the "Robust Simulation" approach advocated by ImageCat as shown in Figure 4.

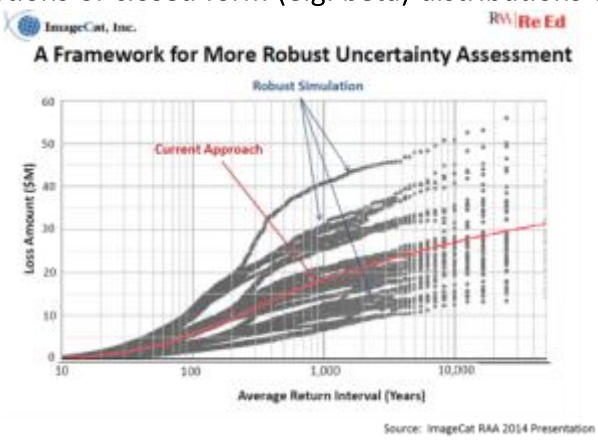


Figure 4 - ImageCat's Robust Simulation EP Curves

- **Correlations.** Correlations are typically modelled between coverages and between locations. Let's take these in turn. For <u>coverages</u>, Oasis provides a range of options from totally correlated to independent sampling to dependent coverages from a primary coverage. Any model that does not include correlations for coverages will give very different results if they should be used. So a model that assumes independence will give lower, and much lower where there are large spreads on uncertainty, accumulated results than one with fully dependent correlations. For <u>locations</u>, correlations can come from hazard intensity and/or vulnerability as described above. Location correlation can, again, cause a major increase in losses compared to assuming no correlation. Many models, though, do not use any location correlation but instead calculate the moments (means and standard deviations) and then aggregate across exposures by computing out the means and correlated standard deviations (as the sum of the standard deviations) and uncorrelated standard deviations (as the square root of the sum of the variances). This approach can be done in Oasis in a similar way for full uncertainty correlating all locations. However, with Oasis it is possible to define groups of locations and their correlation. See APPENDIX D for further discussion of how Oasis handles correlations.

- **"Events, dear boy, events".** A famously alleged response of Harold Macmillan to a journalist when asked what is most likely to blow governments off course. The same could be said of insurance and reinsurance companies! Appropriately termed the "primary uncertainty", the catalogue of events and their severity and distribution over time is the basis of catastrophe modelling. Yet vendor modellers can be cavalier in event set generation and subsequent "boiling down" to small event sets able to fit the computational constraints of their loss models. Karen Clark, founder of AIR, spotted this clearly when she founded Karen Clark & Co and produced "Characteristic Events" based on physical return periods and then applying hundreds of them – for example for US hurricane - for a given return period over the United States. The results were shocking; they revealed the high variability of portfolio losses to the choice of landfalling event (see Figure 5 from KKC). It gets worse – the fewer the events the wider the underlying (and currently hidden to most cat modellers) uncertainties in the Exceedance Probability curves used to estimate Value at Risk capital for Solvency II (Figure 6 from Oasis).

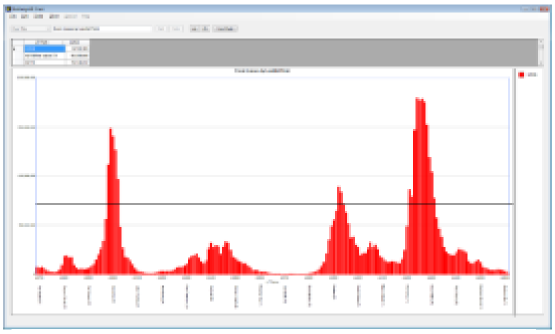


Figure 6 - Example portfolio losses for hurricane landfall Characteristic Events

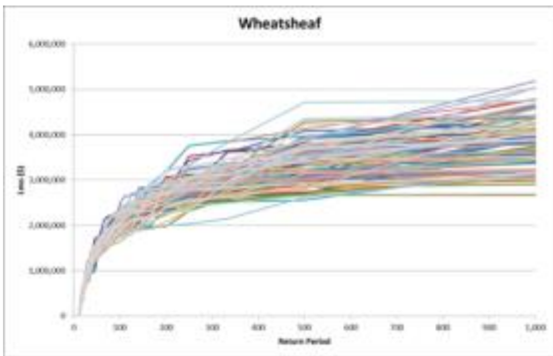


Figure 5 - Dispersion of EP curves (Oasis Toy Model)

These differences can matter. Assumptions for closed form intensity and vulnerability distributions, paucity of event catalogues, and simplifications over correlations can all induce significant differences in outcomes. They also fail to make clear the range of uncertainties in important outputs such as Exceedance Probability curves and Event Loss and Year Loss distributions. There is no guarantee that any of these are unimodal (i.e. single-peaked), yet many models assume beta distributions for event losses and some model software assumes a percentile distribution of EP curve values using (say) a gamma distribution. Why not just calculate out the sample numbers and then do all the statistics at the end? Then we can find out whether the simplifying assumptions were valid or not. But this isn't just a question of intellectual rigour, it has potentially important consequences for pricing (e.g. if the losses are multi-modal then an excess of loss layer from the discrete loss distribution will be different from a smooth closed form such as a beta distribution) and for capital (e.g. if the EP curve is showing multi-modal behaviour – such as two underlying EP curves – then picking the one in-between is quite different from taking a view on whether to believe the high EP curve which could bust your company from the low-end curve where you make a fortune).

GROUND-UP LOSSES

Oasis can be run in a wide range of ways – from deterministic single events with mean intensities and mean damages to fully probabilistic intensity and damage with correlation. The first step in the process is to calculate the losses that can be expected based on the event intensity and damage functions. This is termed the "Ground-up Loss" (known as GULs in Oasis) as it is the estimate of the loss irrespective of any insurance terms and conditions.

GULs apply at the "Item" level in the Kernel which corresponds to "interest coverage" in business terms, where "interest" is the asset at risk and the "coverage" the element of financial loss that can be associated with that "interest". An abstract term like "interest" is preferred to "property" even though that is what we are usually thinking of, because it can refer to total assets for an area (e.g. US county insured values), or the property values themselves, or component buildings and structures. The coverages include damage to buildings, contents, and other structures; accommodation costs; and business interruption costs. A single property can also be broken out (disaggregated) into component buildings or aggregated. Hence the terms "Insured coverage" outside Oasis and "Item" (or "Exposure Item") within the agnostic kernel.

Once we have these GULs, then we can proceed onto the insurance calculation which is what in Oasis we refer to as the "Financial Module" though in common parlance the "Financial Module" often includes GUL calculations.

On Oasis there are three options for calculating GULs:

- **Sampling**. This is the Monte Carlo method relevant if one wants to get the full picture of the loss uncertainties, and the principal method recommended for Oasis users. Sampling inevitably increases the runtimes of the calculations and much of the Oasis development effort has been directed to tuning performance of sampling.
- **Numerical Integration**. This is just calculation of the mean and standard deviation at the lowest level of detail (Item, that is to say, interest coverage). It uses the probability bins and does not require sampling.

- **Sample 0**. This gives the numerically integrated mean in sample format. It can be used to compare sampled values to numerically integrated values but more importantly provides a fast way to run an Oasis model all the way through Financial Module to Output using mean damage. This can provide a valuable sense-check that the data and policies are performing as expected before running the longer and much more data-intensive sampling.

Getting into a position to calculate GULs requires the probability distributions for intensity and damage. After that come the GUL calculation options for sampling and numerical integration.

<u>Generation of Probability Distributions for use in Oasis</u>

Given that the Kernel uses binned distributions, it is necessary to relate a modeller's representation of uncertainty to the Kernel's discrete distributions.

Spreadsheets on the Oasis Members' website and the Oasis "Data Interfaces" specification provide examples of how this works, but in summary it involves four processes – defining the bin structures; generating the event footprint intensity probability distributions; generating the vulnerability probability distributions; and handling correlations. The first three are described in the Oasis "Data Interfaces" specification and in APPENDIX A of this paper.

Correlations are handled in a number of ways in Oasis, but the simplest involves relating the choice of random numbers for sampling the coverages and locations. 100% correlations and pairwise correlations (e.g. between buildings and contents) can be specified in the load of exposures (using the GROUP_ID column and populating the correlation input file). Correlations between hazard intensities (if probabilistic) or between vulnerabilities (if probabilistic) are handled in Oasis using external modeller-supplied APIs (e.g. as webservices); there are no standard methods for correlations such as copulas that anyone wishes to use. This may change.

In the absence of deciding correlation rules by location (which are nearly always important), Oasis, in common with other models, can calculate full correlation and full independence. Oasis does it stochastically rather than by summing variances (for independence) or standard deviations (full correlation).

<u>"Full Uncertainty"</u>

It is tempting to think that by using these probability distributions we are tackling most of the uncertainties in catastrophe models. But this is not so. As explained in APPENDIX D we not only have the "primary uncertainty" of event frequency but also many other contributions most of which loss models do not and cannot reflect.

It is not that helpful simply to say that each insurer or reinsurer should allow for these additional uncertainties, but that is often all we can say within models and the important issue is to recognise the limitations of our knowledge using models.

<u>Fixed Reference Models and Dynamic Sub-models</u>

Oasis R1.5 can used pre-defined tables or API sources of model data

Pre-defined pre-calculated reference model tables for event footprints and vulnerability matrices (and their associated probability distributions) involves defining and pre-loading model files once and then use of the model just looks up the relevant data from these (often large) tables, usually with a further pre-process to define the "Effective Damageability" distribution (see below).

APIs support dynamic definition of the model (e.g. webservice or filter queries) to generate only those model files that are needed for the properties being modelled. This can massively reduce the cardinality of the event footprint and vulnerability matrix tables, which in some cases would be otherwise impractically large, but also allows more complex and IP-protected rules to be provided by the model supplier and maintained as their own code. These APIs can be called from a front-end to Oasis and also from the Kernel.

APPENDIX B describes the API-based "Sub-model" strategy which is one of the strategies explored in the separate Oasis "Sub-model" paper. They are all variants of the precept "generate the sub-model from the exposures (properties) instead of applying the exposures to the already generated general model".

We expect models will in time move entirely over to "Sub-model" strategies rather than today's most common approach of pre-calculated event footprints and vulnerabilities.

<u>Approaches to Sampling</u>

There are four principal ways sampling can achieved within Oasis:

- **The "Full Monte":** This is the simplest way to consider sampling in the Oasis structure of Event Footprints and Vulnerability probability distributions. The idea here is to sample the intensity first and then the associated damage distribution second, and thereby construct a composite sampling structure. This method has not yet been implemented in Oasis as it was computationally more efficient to pre-calculate a convoluted "effective damageability distribution" (see below). However, it is worth bearing in mind that where event footprint intensity correlations by location are needed, the "Full Monte" would be relevant.

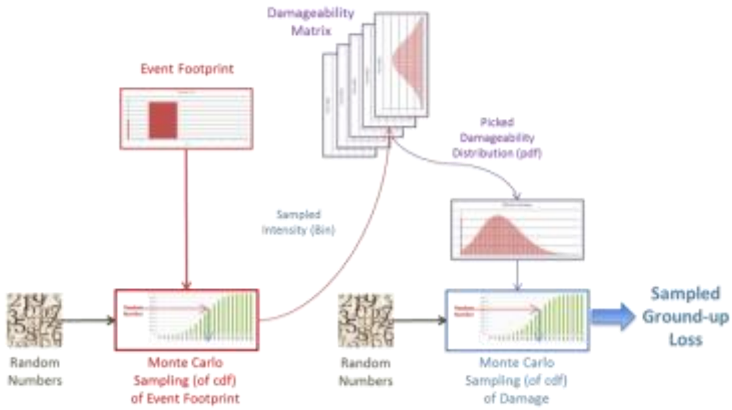


Figure 7 - The "Full Monte" Method

- **Effective Damageability Distributions:** this is the method currently in use in R1.1 and R1.5 of Oasis. It pre-computes a single cumulative distribution function (CDF) for the damage by "convolving" the binned intensity distribution with the vulnerability matrices (shown in Figure 8 as a family of "Damage State Distributions").

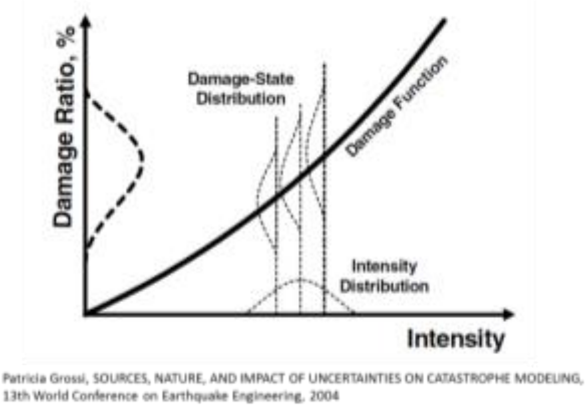


Figure 8 - Effective Damageabilty - The Idea

  Sampling can then be done against the single CDF rather than twice as in the "Full Monte" as shown in Figure 9 which also shows how we do the convolution. We compute the probability masses (termed the "pdf", probability density function) first then construct the CDF.

  Because in many cases there is a standard set of event footprint and damageability combinations (e.g. for a particular area) and the computation of CDFs can be computationally laborious, then "Benchmark" CDFs can be pre-computed and additional distributions are generated incrementally when a portfolio of exposures is applied. For instance, there might be a portfolio which is primarily for Yorkshire, but there are a couple of properties included from Lancashire. Then using the Yorkshire Benchmark makes sense and the few properties from Lancashire get their additional CDFs at runtime.

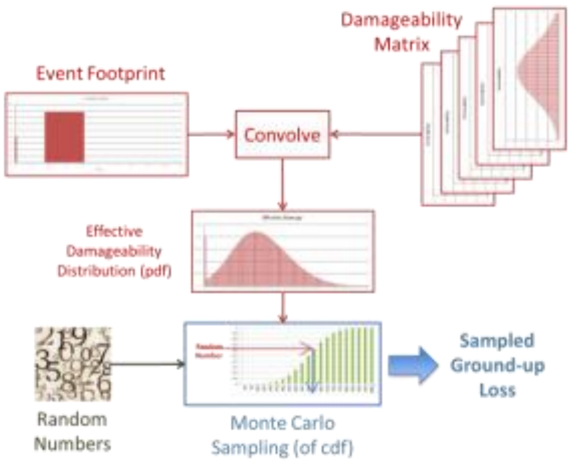


Figure 9 - Effective Damageability Method

- **Intensity Ensembles:** Ensembles are a general way in which uncertainties can be expressed in Oasis (for example, multiple event/year sets). The idea is that there are many different assumptions (and samples of these assumptions) which can be weighted at source (termed "model fusion" as opposed to merging results at the end which is the practice termed "model blending"). Model blending can be dangerously misleading if it blends after aggregating and averaging. This can lead to losing detail of the uncertainty, akin to crossing a river which has deep water in the middle but on average is 3 feet deep.

  The method of using ensembles for intensity is also useful for representing location correlations. What happens is that an Event provides a set of "Event Realisations" (samples of the footprints) which then can be played through the second damage sampling to provide a full set of samples of both intensity and damage ("The Full Monte" – see above).

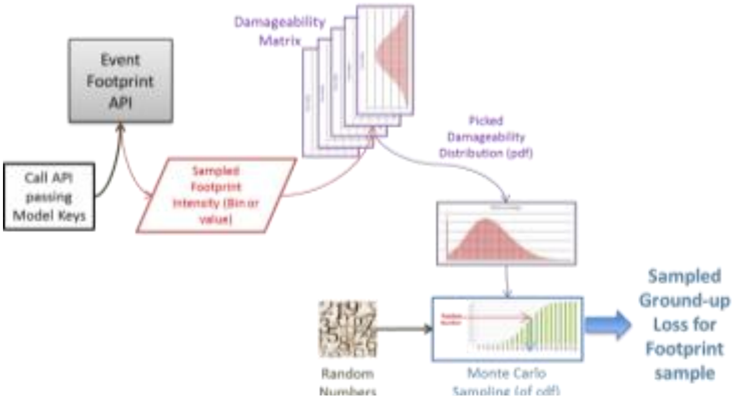


Figure 10 - Ensemble Method

- **The "Full API":** This is the extreme case of handling damageability where a call is made (to a "connector" typically) that invokes APIs from the model supplier's systems. Figure 11 shows how this works using a "connector" (which can be secured) to the supplier's APIs. This allows a wide range of source provider formats and options, but the connector is part of the supplier's model and not maintained by Oasis.

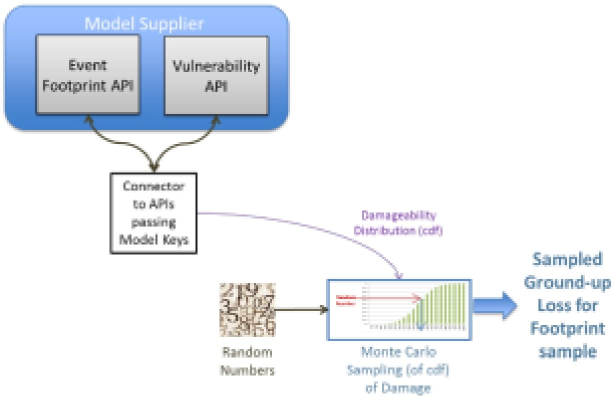


Figure 11 - "Full API"

There are further options such as dynamically requesting the sampled damage directly from a model supplier's API. This means the entire sampling process would be handled externally.

<u>Use of Interpolations</u>

Oasis R1.5 uses histogram bins each with uniform probability density functions (pdfs) (i.e. fat tops!) so generally invokes <u>linear</u> interpolation for sampling of the associated cumulative distribution functions (cdfs). However, it is also be possible to use linear pdfs and invoke quadratic sampling of cdfs. APPENDIX E describes these options and the reduction of discretisation errors that can be assisted with quadratic sampling.

Methods of Random Number Sampling

As described in the Oasis "Sampling Strategies and Convergence" paper, there are more strategies for sampling than simple "brute force" random numbers taken uniformly from the interval [0,1]. These include stratified and antithetic sampling which can in some cases dramatically reduce the number of samples needed to achieve convergence.

There are further options such as use of SOBOL random numbers (see, for example, http://people.sc.fsu.edu/~jburkardt/py_src/sobol/sobol.html) which can achieve similar benefits by reducing the "white space" between random numbers. Oasis R1 uses only "brute force" but does allow pre-defined tables of random numbers so it would be easy to implement SOBOL sequences and stratified and antithetic sampling.

Numerical Integration

It is commonly asked why Oasis doesn't just use numerical integration and, as has already been explained, this is because the application of policy terms and conditions can be very complex and is usually highly non-linear ("excess of loss" policy terms). Whilst there is a computational cost for sampling, the benefits of applying insurance structures easily outweighs it especially as it means assumptions need not be made about the output event loss tables.

Oasis nonetheless provides an option to compute mean, variance and standard deviations for each location coverage called "Analytics" in Oasis. The usual statistical tricks can then be applied to them to construct aggregated means and correlated and uncorrelated aggregate standard deviations. These "Analytics" run very quickly so if one wished to assume a beta distribution for location coverage event losses and either use that for policy calculations and re-sample from that (as at least one modelling company does). From an Oasis philosophy, though, it would be absurd to lose or mask the uncertainty information (see Outputs section below).

OASIS FINANCIAL MODULE (Policy Terms and Conditions)

Applying Policy Terms and Conditions

The overall architecture of Oasis for computing out the policy terms and conditions is shown in Figure 12. In the general architecture the use of moments and fitting to distributions and re-sampling is possible. And indeed anyone could easily modify the Oasis code to achieve this. However, at present we are aiming to avoid assumptions and simplifications, so Oasis R1.1 and R 1.2

Figure 12 - Oasis General Calculation Architecture

only provide the full sample set, which are propagated forward to the policy terms and conditions as if they were a large number of event realisations. Figure 13 shows this approach.

This can be changed for future releases if the demand is there or if the open community develops the code (assuming anyone wants it!).

Figure 13 - Oasis Release 1 Calculation Architecture

Insurance Structures

Insurance policies have terms and conditions applying at many different levels and with many variations in the rule of calculation. Some of the simplest are shown to the right, but there are many variations and the interested reader is advised to consult the Oasis website for actual examples. Here we shall look at the structural side as that is what makes the calculations tricky. The diagrams work from bottom to top, with the ground up losses coming in at the bottom and the insurance losses popping out at the top:

- **Simplest**: this is when the ground-up losses are accumulated to the highest level and policy terms and conditions applied. There could be many policies (termed "layers" in Oasis) applicable to the same aggregation (termed a "programme" in Oasis).
- **Simple**: The next level of complexity is to include coverage terms such as location coverage deductibles (such as a buildings or contents deductible - these are very common) and then aggregate the net figures up to the policy level for the excess of loss. In R1.1 and R1.5 today, application of coverage terms is done separately in FM (the "Financial Module" for the policy terms and conditions calculations), but these may be done as part of the ground-up loss calculation in future releases.
- **Simplish**: The next step is to apply location terms such as limits, before summarising up to the location level after coverage deductibles. The results of these calculations are then fed up to the overall policy terms.
- **Less Simple**: Another stage of complication is when the higher level is based on aggregations which have already been suppressed in calculating a lower level. An example

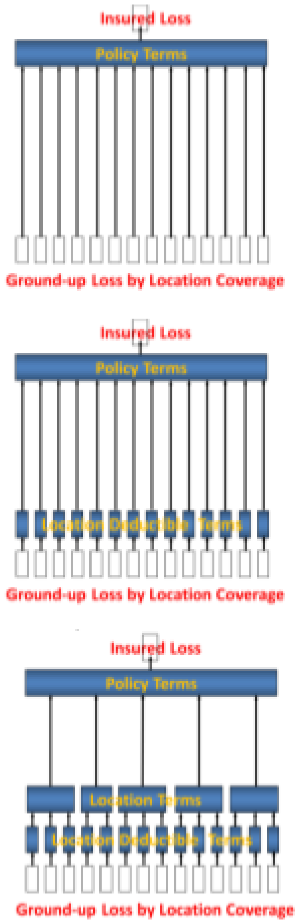
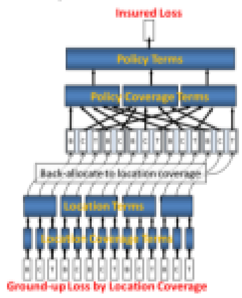


Figure 14 –Simple Insurance Structures

is where policy coverage deductibles and limits are applied after location terms. Here the post-location losses have to be "back-allocated" to the coverage level (usually in proportion to the proportion of coverage to the post-location losses) and then aggregated.



- **Complex**: And then we have a myriad of cases where terms and conditions apply at many levels, from location coverage to location to locational areas (e.g. municipalities) to areas where perils are sub-limited, to policy coverages and then to the policy as a whole. At each level there can be different policy terms applied. These can be very complex indeed revealing the appetite of underwriters to put in conditions whenever there is a loss!

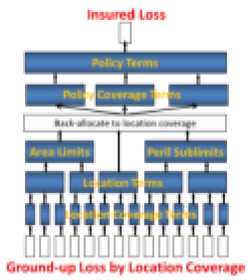


Figure 15 - Complex Insurance Structures

FM Processing

The general way Oasis deals with these insurance structures is to follow the "level" logic and apply iteratively. Figure 16 shows how each level is processed, with stages for:

- **Unify**: brings together relevant Items to process.
- **Filter**: decides which of these to include.
- **Aggregate**: sums up relevant data to specified level.
- **Calculate**: computes insurance recovery.
- **Allocate**: back-allocates to Item level (if needed).
- **Save**: saves data for the next round of processing.

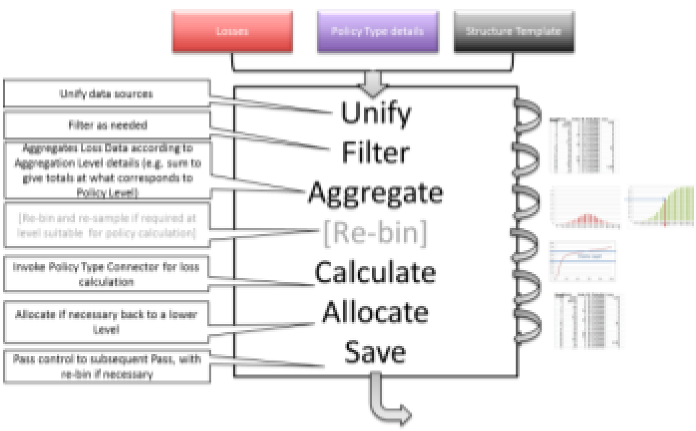


Figure 16 - FM Calculation Components

There is also a greyed-out [Re-bin] option which represents the potential for re-binning if performance was a problem.

The logic for generating the appropriate tables to drive the FM calculation is shown in an Excel spreadsheet, the "FM Wizard" which takes the user through a series of questions to define the structure and data values in these tables. What this amounts to is a scripting language, which in future versions we may develop into a full "Contract Definition Language".

In the Oasis FM, these processes are orchestrated by data tables giving information on the levels and aggregations and allocation rules, together with back-allocation.

For details of how the data interface files are constructed to represent these structures, please see the Oasis "Data Interfaces" specification. In brief, the Oasis Kernel for Policy Terms and Conditions, which is termed "FM" in Oasis, needs the following four files:

- what is to be insured (the collection of exposure items, the "Programme");
- what is being applied (the "Layer");
- the calculation rule that applies (the "PolicyTC"); and
- the specific policy terms and condition values and rules ("Profile").

In addition, there can be a dictionary for Programme and Account details called Prog which, in conjunction with Layer, provides the composite key of a policy in Oasis.

Reinsurance Structures

Reinsurance structures have some similarities to the insurance policy calculation structure in that they take the losses after one level of calculation as the input to the next level, often with back-allocation.

Reinsurance structures are shown top-down from gross (i.e. insurance) loss to reinsurance recoveries as shown in Figure 17 for a simple reinsurance programme.

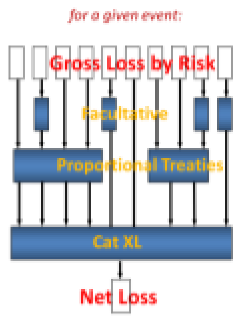


Figure 17 - Simple Reinsurance Programme

More typically, however, there can be risk excesses and line of business covers which then go through the whole account excess of loss, as shown in Figure 18.

In these cases processing the outwards reinsurance is a complicated suite of processing and at each stage there can be the need to back-allocate to the originating risk-level data. This is akin to the insurance calculation need to back-allocate to location coverages.

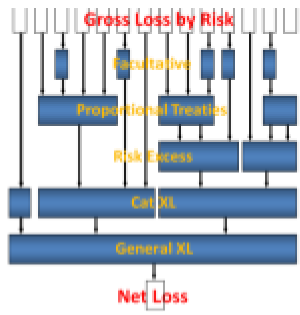


Figure 18 - Complex Reinsurance Programme

The associated systems architecture is more general than for insurance, with iterative sequences of processing including links to external calculations of derivative products such as cat bonds.

Handling of reinsurance UNL structures forms part of Release 2 of Oasis, though simple inuring reinsurances will be accommodated in R1.5.

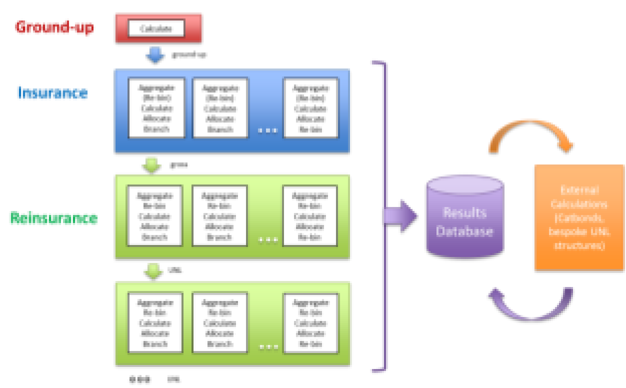


Figure 19 - Generalised FM Calculation

"A theory is more impressive the greater the simplicity of its premises, the more different types of things it relates and the more extended its areas of applicability."

A Einstein *Autobiographical Notes* **33** 1946

APPENDIX A GENERATING OASIS PROBABILITY DISTRIBUTIONS

As described in the Oasis Data Interfaces Specification paper, connectors provide the translation of a source model's parameterisation of event footprint intensity and vulnerability into the kernel's probability distributions. This Appendix provides a summary of this process relevant to the definition of the Oasis Kernel's calculations.

Intensity and Damage Bin structures

Probability bins are used in the Oasis Kernel for intensity and damage. At present these are fixed bin structures (but with variable bin sizes and allowing for closed intervals) for a given model so are part of the model definition to Oasis. Typically the intensity bins include a [0,0] value to allow for "miss factor" and the damage bins include a [0,0] bin for no damage and a [1,1] bin for total loss. A single point distribution can be binned to a defined structure (depending on the way vulnerability is defined) or set as a closed interval for the single point.

Event Footprint (Hazard) probability distributions

Event footprints in Oasis are relative to definitions of Event and Location for a Peril. There are many ways location is defined in different models such as Cresta zones, post/zipcodes, grids, variable resolution grids, polygons, and co-ordinated cells. These vary by peril and many models offer multiple options (e.g. Postcode or grid points) according to the availability of exposure data. Whichever location definition is chosen for whichever peril, the list of valid values for the combination is known in Oasis as an AreaPeril dictionary and any business front-end system needs to pick the appropriate AreaPerilID. Multiple perils can be handled by multiple EventIDs with an Event Dictionary identifying the common "Event". Occurrence of an Event can be defined with the model-specific Event Profile (e.g. as a year number) or through a separate cross-reference table which allows the same event to be used more than once in the Event Year set. Oasis provides options for single (scalar) metric values or binned probability distributions. Single point values can either be binned or their value can be the bin. Multiple metrics can be treated in the same way and applied to different coverages (e.g. buildings might use spectral acceleration and contents use peak ground acceleration) or combined against one coverage (provided there is an associated damageability matrix. Where data are not provided in native Oasis format of binned probability values, a "connector" (maybe with an API if dynamic) is needed to take the model's view of intensity and convert it into an Oasis-computable form.

For instance, flood depth intensity for a postcode might be defined using three parameters - the proportion of the postcode that has flooding and the lower and upper bounds for maximum flood depth. In this case the probability distribution is a Dirac delta function at zero intensity then a uniform distribution between the lower and upper bounds with area of the proportion of the postcode that has flooding (see Figure 20).

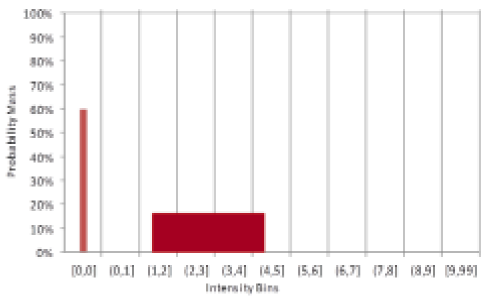


Figure 20 - Analytic Distribution of Flood Intensity

The "connector" has to apply the bin structure at the lower and upper boundaries with interpolation such that the total area of the binned histograms resulting is equal to the proportion of the postcode that has flooding. This is shown in Figure 21 where the end points are lower in proportion to the lower and upper bounds (in this case 1.2 and 4.1 metres flood depth)

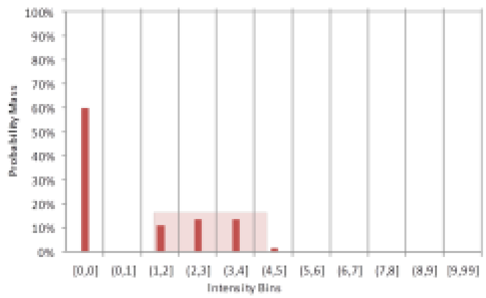


Figure 21 - Discretised Distribution of Intensity

Damage (Vulnerability) probability distributions

Most extant loss models have a limited number of combinations of probability distributions reflecting vulnerability so they can be pre-computed. The need for pre-computation is particularly where the peril intensity is a probability distribution. For many models, the intensity can be a point value rather than a distribution so all that is needed is to pick (see below for interpolation) the relevant vulnerability function. For high fidelity models, though, the vulnerability functions can be bespoke to a property so need to be dynamically calculated. This can be done with API (e.g. webservice) calls to a (local or remote) server. The general case has a combination of the intensity and vulnerability probability distributions.

The way many models express the relationship between intensity and vulnerability (damage) is through a plot for a set of discrete values of intensity and the mean and standard deviations of the associated damages (these are then often assumed to be a certain closed form probability distribution, as we shall shortly describe). An example of this plot for flood depths is shown in Figure 22.

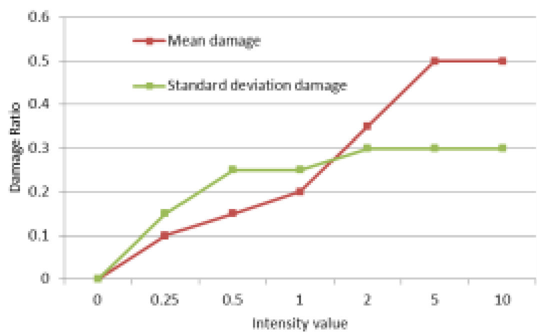


Figure 22 - Typical Vulnerability Curve

In order for this to be used in the intensity bins, this value has to be interpolated in order to find a value of the mean and standard deviation of damage for the bin – this is usually done as a linear interpolation of intensity as shown in Figure 21 where the point values of 0 and 0.25 for the mean and standard deviation are linearly interpolated to give the values for the 0.05 and 0.15 intensity values (these being the mid-points of the (0,0.1] and (0.1,0.2] intensity bins).

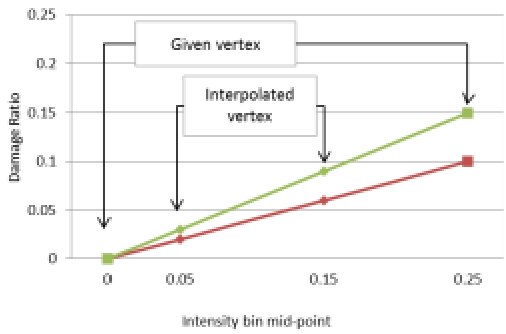


Figure 23 - Intensity Interpolation

Having values for the relevant probability distribution parameters (in this case the mean and standard deviation), the model will usually have a distribution, often closed form such as a truncated normal distribution, with truncated values going into the end points. These are then calculated for each bin mid-point in a "connector" as shown in the diagram to the right. Note that the mean and standard deviation of the resulting distribution is not the same as that of the source distribution, and this distortion will be particularly noticeable at the end points. The model developer should therefore take into account the effect of truncating unbounded distributions such as the normal or lognormal or gamma distributions when setting the putative values of the mean and standard deviation for the truncated distributions. When you put all this together you get a full family of damage distributions by intensity which can then be "convolved" (weighted) by the intensity bin probabilities to create an "Effective Damageability" distribution for the event footprint vulnerability combination (see main text). For the many cases where intensities are point values, it is only necessary to pick the (interpolated) damage function. For cases where there are intrinsic correlations of intensity, then the sampling of the random numbers could be done using the "Full Monte" (see main text) if some correlation rule could be defined or, more likely, simply call the model using an API as we shall now describe.

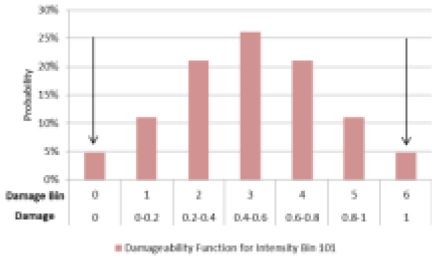


Figure 24 - Truncated Normal Distribution

APPENDIX B SUB-MODELS

As described in detail in the Oasis Sub-models paper, there are many ways that sub-models can be generated to use in Oasis. One such is a “Simple Sub-model” as shown in Figure 25 where the model provider makes the full model dictionaries available in the hosting environment for the model using Oasis webservices.

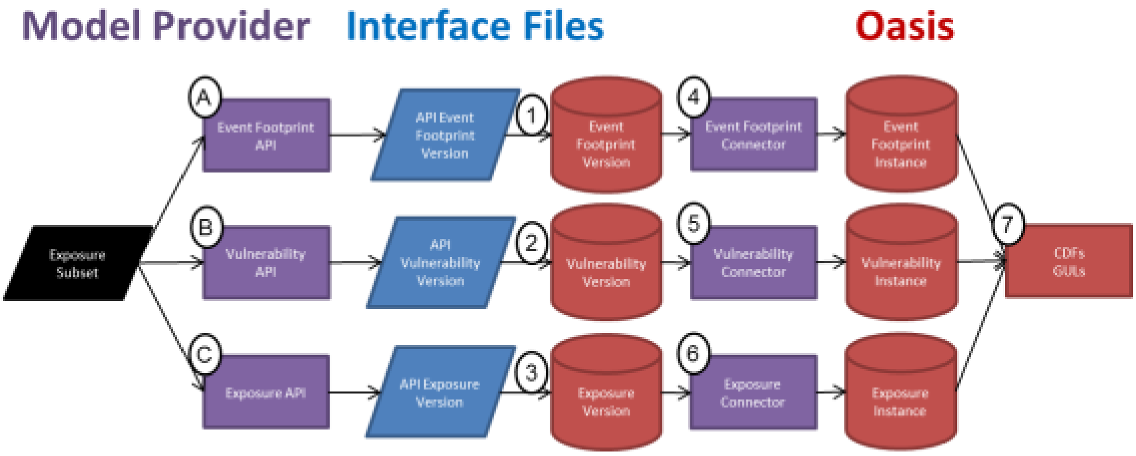


Figure 25 - Simple Sub-model

Front end/model generator controlled processes;

A. Generate an event footprint file from the source exposure data in Oasis native format
B. Generate a vulnerability file from the source exposure data in Oasis native format
C. Generate the exposure files from the source exposure data in Oasis native format

Oasis processes, controlled by webservices invoked by the front end;

1. Create / run sub model hazard footprint version
2. Create / run sub model vulnerability version
3. Create / run exposure dictionary and exposure module version
4. Create / run sub model hazard footprint instance
5. Create / run sub model vulnerability instance
6. Create / run exposure module instance
7. Run benchmark / CDF / GUL tasks

APPENDIX C OUTPUTS

Not strictly to do with the Financial Module, but we add a few comments about Oasis outputs as the calculations in the kernel affect the outputs.

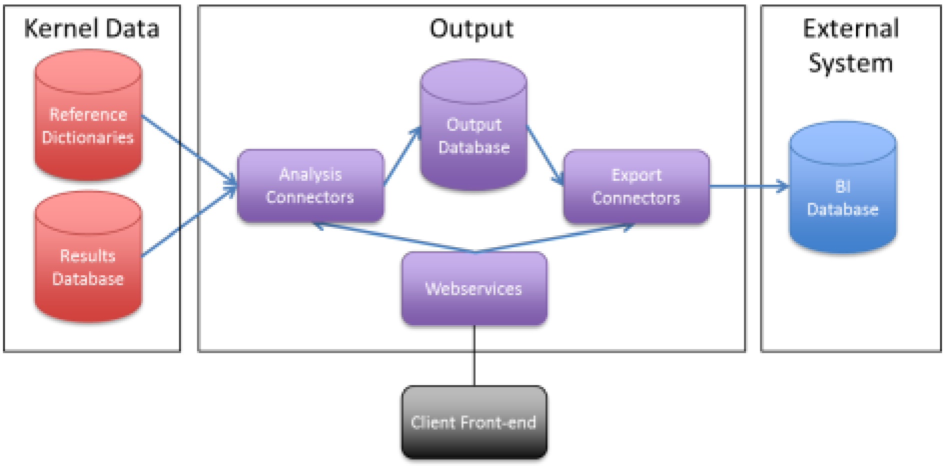


Figure 26 - Output Architecture

Figure 26 shows the architecture – the calculated results are joined in SQL queries to reference dictionaries whether those used in input such as the AreaPeril or Event or Exposure dictionaries or additional user-defined dictionaries for the purpose of output.

The outputs from the SQL queries in the "Analysis Connectors" are stored in an "Output Database" and can then be exported using "Export Connectors" in a format required by an external data store.

Of the many outputs (for further details see the Oasis Outputs specification), of particular interest are EP Curves and Event Loss Distributions.

EP Curves

The Exceedance Probability or "EP" Curve, also known as the Value At Risk or VaR curve, plots the probability of exceeding a certain level of loss. You might have thought there was only one way to do this, but there are many. At the most basic level, the current modelling companies fall into two camps on this calculation. First, those who use event frequencies (arrival rates) to calculate an "Occurrence" EP (OEP) curve or the plot of the largest loss from any one event in a year. In this case an algorithm using arrival rates can be used readily. Second, those who use relative frequency and event/year simulations to calculate annual losses either on an aggregate basis called an Aggregate EP (AEP) curve, or an occurrence basis (OEP). These are calculated on a simple relative frequency basis. The second method has genuine advantages for AEP curves as the event occurrences by year (indeed by date) form part of the model and so can incorporate time correlations or "clustering" of events. The former method really isn't much good for AEP and requires assumption of an arrival distribution such as Poisson or Negative Binomial (which are very crude compared to the modelled correlations) and then a convolution which usually requires Fast Fourier Transform techniques to solve numerically.

The EP curves so calculated can themselves take on several forms depending on how they are computed.

Figure 27 shows three principal options which, as you can see, give different plots:

- **EP curve of means**: Take all the mean losses and rank order them across Years simulated
- **Mean of Wheatsheaf EP curve**: EP curve of a metric of the samples (in this case the mean of the sample EP Curves, though could be the median, very little difference).
- **Full EP curve**: where each sample is treated as a resampling of the annual events (e.g. 10 samples from 10,000 years becomes samples from 100,000 years).

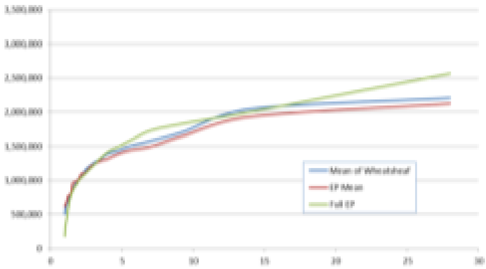


Figure 27 - Comparison of EP Curves

Of particular interest is the graph showing plots of all the samples' EP curves themselves which in Oasis we term a "Wheatsheaf" as shown in Figure 28. What this example shows clearly is "multi-modal" behaviour which is that the distribution of EP curves is not simply a case of variations around a central tendency. This is also highlighted in ImageCat's "Robust Simulation" approach (see "Calculation of Losses" above).

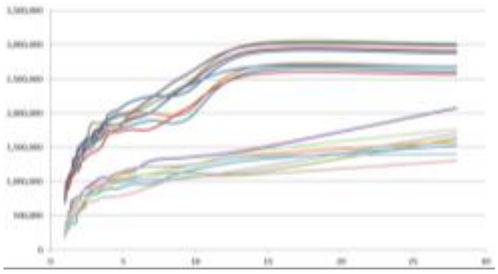


Figure 28 – Multi-modal Wheatsheaf

Taking another example, in which we do see central tendency, Figure 29 shows a large dispersion around the mean EP curve (however this is calculated). It is worth noting that the spread is not a function of number of samples (it only improves the resolution of the spread distribution). Instead the spread of a uni-modular distribution can be reduced by increasing the number of events or number of similar exposures.

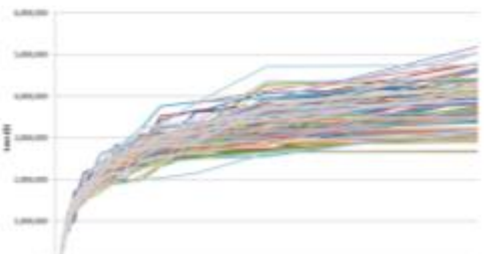


Figure 29 - Wheatsheaf from a "Toy Model"

It is also worth noting that the Mean of the Wheatsheaf is a good estimator to the final distribution and, as Figure 30 shows, can differ from the EP curve of the means (the latter being a poor estimator). Applying policy terms to this ground-up loss Wheatsheaf gives a different distribution as shown in Figure 31, where the losses are capped at the limit but break through when there are multiple occurrences in a given year (limit assumed not reinstateable).

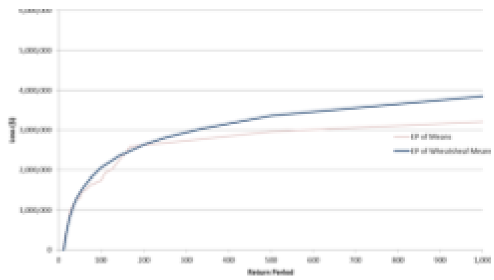


Figure 31 - EP Curves from a "Toy Model"

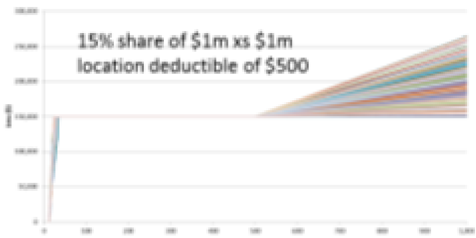


Figure 30 - FM Wheatsheaf

Event Loss Distributions

As well as EP curves, Oasis stochastic calculations reveal the underlying Event Loss histograms. For example, Figure 32 shows the actual distribution (in red) compared to the beta distribution assumption (ground-up loss, with beta distribution fitted using the numerically integrated moments).

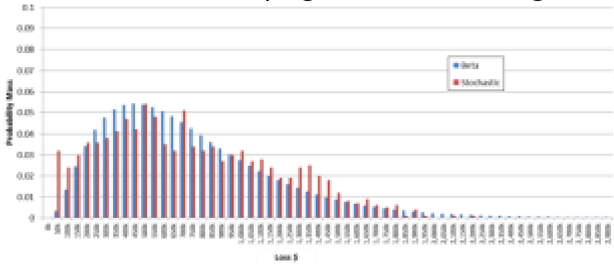


Figure 32 - Event Loss Distribution vs Beta Distribution

Ensembles

It is worth noting that these uncertainties are only a small part of the picture. In the wider case of loss models representing reality then, as discussed in APPENDIX F, we have many additional factors coming into play.

One way to handle some of these, in particular those that relate to uncertainties in the science or data, is to use "ensembles" to represent epistemic (i.e. lack of knowledge) uncertainty. An ensemble in this sense is a set of different source assumptions. To some extent this can already be represented within the usual framework by allowing probability distributions (e.g. for vulnerability), but it is possible to go further. Ensembles that represent different weightings of assumptions can be played through the model to produce more complete output distributions reflecting our beliefs about theories or knowledge of reality.

And this could, in principle, be taken further to an iterative adjustment of our beliefs based on experience using a Bayesian framework. The ensemble output distribution can be compared to actual results and the chance of those assumptions producing the observed output used to adjust the assumption (prior) probabilities. Although this has not yet been done, it will be addressed as part of an Oasis multi-model modelling Working Party in 2015.

APPENDIX D HANDLING OF CORRELATIONS IN OASIS

Correlation in the sense used for Oasis means a dependency between the sampling of one (random) variable and that of another. For instance, if buildings and contents damage is 100% correlated for a property, then sampling of these coverages should use the same random number.

Oasis supports various types of correlations:

1. Random numbers (indexed by GROUPIDs), which assign random numbers to coverages and provides options for fully correlated or fully uncorrelated.
2. Pairwise correlated random numbers (see Figure 33) In this case a Pearson Correlation Coefficient, r, is used to use a second random number to generate a random number that is correlated to a given random number. The method is shown in the tables below

Random Number Table

GroupID	Random No
1	0.51400
2	0.96218

Correlation Table

GroupID1	GroupID2	r
1	1	1
2	1	0.5

r is the Pearson Correlation Coefficient between two random variables

The formula for the correlated Random No is:

$$\left(R_1 * r + R_2\sqrt{1-r^2}\right)/\left(r+\sqrt{1-r^2}\right)$$

Correlated Random Number Choice

Property	Coverage	ItemID	GroupID	R_1	R_2	r	Random No
1	B	1	1	0.51400	0.51400	1	0.51400
1	C	2	1	0.51400	0.51400	1	0.51400
1	BI	3	1	0.51400	0.51400	1	0.51400
2	B	4	2	0.96218	0.51400	0.5	0.67805
2	C	5	2	0.96218	0.51400	0.5	0.67805
							67805

Figure 33 - Pairwise Correlation

3. Correlation matrix (not implemented in R1.5 ktools), where a multiple sampling of random numbers is performed but from a matrix (or more generally, a hypercube) such as a percentile correlation (copula) or rank-ordered correlation. The idea here is that some random variables underlying the GROUPIDs have a relationship to each other such that the random numbers are chosen for each GROUPID using a rule that relates them together in a matrix. A way that this can work is to pick the random number for a second variable contingent on the value sampled from the first value or, more generally, random numbers are sampled for each variable by sampling from a copula. Further details of what could be done can be provided, but as yet we have had no examples of this type of correlation and there was no interest in copulas in the 2014 Correlations

Working Party. However, this can be implemented by creating a variant of ktools on R1.5.

4. Conditional values. Here, the sampling is from, say, Buildings, but the other coverages (e.g. Contents and Business Interruption) are determined from the sampled damage using a deterministic relationship (with suitable interpolation). This reflects the correlations that can be obtained from loss data. An example of this has been creaed for ARA's model using aratools based on Oasis R1.5.
5. Conditional sampling. Here, a primary sampling is from, say, Buildings and Contents to give Property damage and the other coverages (e.g. Business Interruption) then use a distribution which is conditional upon the property damage.This would be delivered using the ktools framework in R1.5.

Running Oasis for fully correlated and uncorrelated.

In many cases, though, there is no decent knowledge of the correlations due to factors such as location. One way to deal with this is to take the basic or pairwise correlations by coverage and then undertake these entirely independently (uncorrelated, the default) or dependently (pick the same random numbers for all coverages in any group deemed to be correlated). All of this can be controlled in Methods 1 and 2 by setting the GROUPID in the ITEM table and, if needed, set the CORRELATION table as well. For instance, one might say that all properties in the same estate are correlated but between estates they are independent.

For the second moment, a popular method is to take a linear combination of the standard deviations of the correlated and uncorrelated losses. This is, though, largely unjustified, so more likely better to run with and without correlation (using GROUPID) and consider the range. Another way would be to generate an ensemble of different correlation assumptions

[Note that for fully correlated losses then the standard deviation of the sum of the variables is the sum of the standard deviations and for fully uncorrelated, the variance of the sum of the variables is the sum of the variances, which means the standard deviation is the square root of the sum of the variances].

APPENDIX E HANDLING OF INTERPOLATIONS IN OASIS PROBABILITY SAMPLING

Within the Monte-Carlo sampling calculations of Oasis there are two ways in which the value of the associated variable can be determined from the random number applied to the cumulative distribution function – linear and quadratic interpolation. Release 1.3 will include quadratic interpolations as well as linear interpolations.

Linear Interpolation

In this case we have a pdf which is histograms for ranges, shown as blue blocks in Figure 34, with possible Dirac delta functions (probabilities of non-zero mass for point values) as shown by the red dots in the top diagram of Figure 34.

The associated cdf is linear (by integration) between the histogram end-points (as open intervals) with possible delta functions at these end-points shown by vertical discontinuities as shown in the lower diagram.

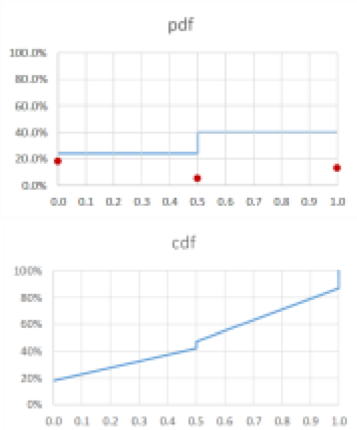


Figure 34 - Linear cdf

The associate interpolation of the cdf is then linear as shown in Figure 35, which includes the interpolation formula.

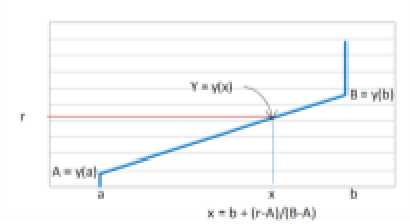


Figure 35 - Linear Interpolation

This is the method used in Oasis R1.5 as all probability density functions are histograms and so uniform within the range, and all cumulative distribution functions are linear.

Quadratic Interpolation

Another method, to be supported in R1.5 is quadratic interpolation where the probability density can be linear as shown for the special case where it is fully linear in its range in Figure 34. It could, however, be somewhere inbetween and indeed be simply a histogram as in Linear Interpolation.

The gradient in the case shown gives rise to quadratic cdfs (again for the special case where the pdf for the histogram is maximally linear) and associate interpolation as shown in Figure 37:

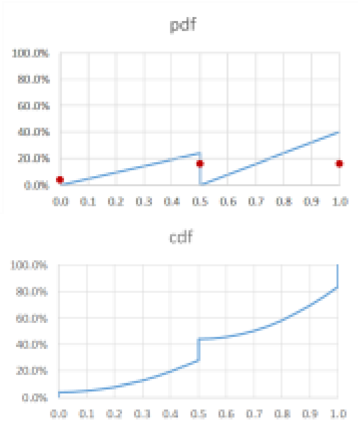


Figure 36 - Fully Quadratic cdf

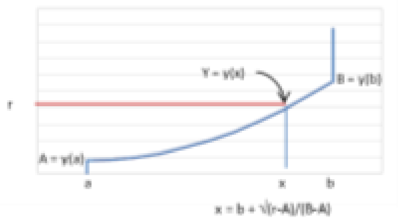


Figure 37 - Fully Quadratic Interpolation

APPENDIX F UNCERTAINTY IN CAT MODELLING

Models are representations of a problem for which we have some inputs and rules with which to drive some useful output metrics. For catastrophe risk assessment these metrics include average annual losses (the "technical rate") for pricing and a percentile of annual losses needed for capital reserves as determined by, say, a regulator – for instance, Solvency II requires 99.5% of predicted annual losses to be held as capital.

Any particular model takes inputs of data and assumptions, so this gives the potential for uncertainty in three areas – the data, the model itself, and what the model doesn't cover. In catastrophe loss modelling terms, this picture looks like Figure 38.

Model Uncertainty
Model Inadequacy
Model Risk
Parameter Risk
Calculation Error

Data Uncertainty
Wrong location
Understated Values
Building Risk profile
Schedule out of date

Unmodelled Uncertainty
Secondary Perils
Contingent BI
Policy Wordings
Loss Adjustment Expenses

Figure 38 - Sources of Uncertainty

Model Uncertainty covers the uncertainties that exist within the scope of the model. *Model inadequacy* represents the unsuitability of the underlying physical hazard and vulnerability models, as well as the effect of ignoring secondary perils such as demand surge (sometimes termed Loss Amplification) and fire following earthquake, or secondary coverages such as business interruption (BI). *Model risk* is the risk that the particular model is wrong or provides an incomplete and misleading picture. *Parameter risk* is the risk that the model's parameters (often expressing assumptions or calibration factors) are wrong, and *calculation error* the risk that the model has been insufficiently discretised or sampled.

Data Uncertainty in this case applies to information describing the insured exposures which are typically properties and structure. This can cover *location* which is generally the most important attribute of an interest (such as a building), and *understated values* where, for various reasons (including *out of-date* schedules), the insured values do not reflect the indemnity that would be incurred. Data uncertainty can also include the *risk profile* of a building, i.e. the attributes that characterise propensity to damage - "primary modifiers" such as construction and occupancy, plus "secondary modifiers" which are other attributes that affect damage such as a roof geometry. And of course, any data may be *out of date,* as is so often discovered when a catastrophe occurs and a building is damaged which is not on the schedule used for underwriting.

Unmodelled Uncertainty is set apart from the data and the model as it relates to the part of the representation of the problem that is outside the domain of the model. It covers a range of factors, which include *secondary perils* such as business interruption, demand surge, and fire following (although these can sometimes are included in the model and any weaknesses would then fall under "Model Inadequacy"). A particular cause of unmodelled loss in recent years has been *contingent business interruption* losses caused by supplier failure. The interpretation of *policy wordings* by the relevant jurisdiction can also materially affect losses, and a component of insurance cost generally ignored by modellers is the expenses and fees from adjusters and lawyers and other third parties involved in a claim, termed *loss adjustment expenses*. In some cases these can be a material overhead on top of the pure indemnity cost.

All of these factors go into the risk assessment process and contribute to cost and cost uncertainty, so it is worth checking how many of the uncertainty factors get addressed when looking at a particular model.

SOURCES OF UNCERTAINTY IN CATASROPHE LOSS MODELS

There are many sources of uncertainty within catastrophe loss models, and categorising them is somewhat arbitrary, but here's a suggested taxonomy:

Area	Uncertainty	Description	Type of Uncertainty
Primary – Event	Frequency	How often does this event occur?	Model – Parameter Risk
	Clustering	How correlated (or independent) are events in time?	Model – Parameter Risk
Secondary - Event Footprint	Choice of peril intensity	Which measure of intensity is appropriate (if any) as a driver of damage?	Model – Parameter Risk
	Peril intensity	Given the measure, how uncertain is the intensity?	Model – Parameter Risk
Secondary – Vulnerability	Vulnerability	How does vulnerability vary by type of property?	Model – Parameter Risk
	Damageability	Given a property suffers the peril intensity, how uncertain is the damage?	Model – Parameter Risk
Exposure Data	Data quality	How accurate and precise are the property data?	Data (general)
	Location correlation	How does damage uncertainty correlate due to location?	Data – Wrong location
Stochastic Modelling	Discretisation error	What errors are introduced due to discretisation (choice of probability bins)?	Model - Calculation Error
	Sampling error	What confidence level is associated to random sampling?	Model – Calculation Error
Socio-economic	"Loss amplification"	How uncertain are loss cost estimates as a function of size of catastrophe?	Model – Model Inadequacy
	Legal judgements	How uncertain are rulings of liability?	Unmodelled – Wordings

Figure 39 below shows where each of these applies in the loss modelling process:

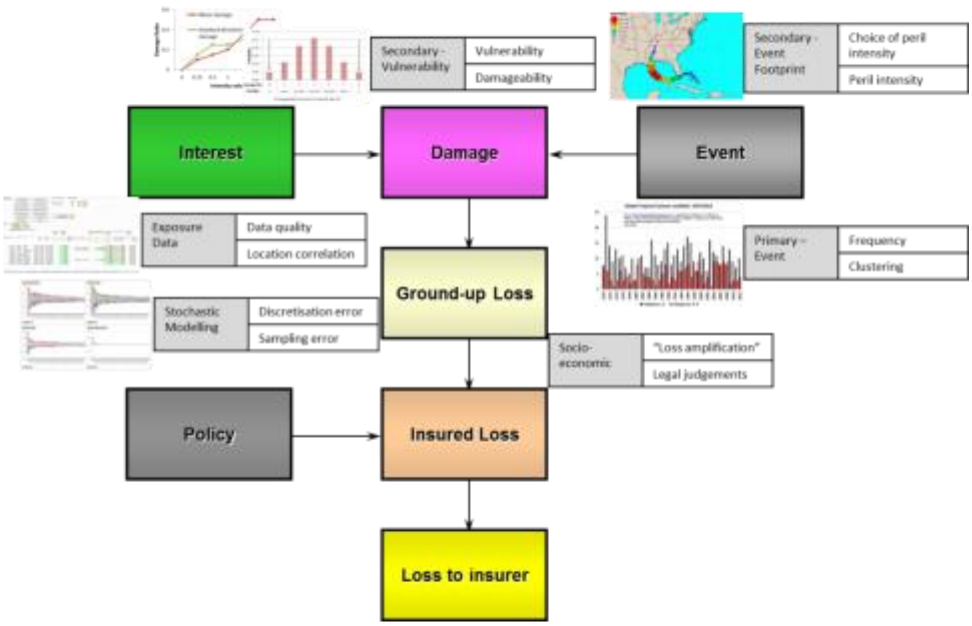


Figure 39 - Uncertainties in Cat Models

What is then particularly interesting is that many sources of uncertainty lie outside the model as shown in Figure 40:

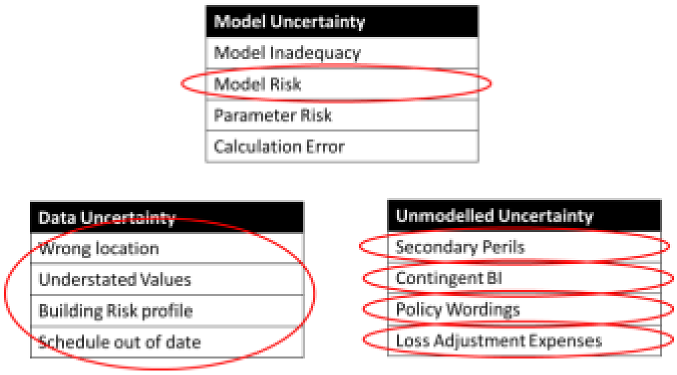


Figure 40 - Key Uncertainties outside the Model

The principal concerns are model risk and the unmodelled uncertainties. Model risk is a problem to which solutions are being developed, and is covered in the next section. Unmodelled uncertainties need to be allowed for with judgement and subjective allowances, and some may in due course be brought under the modelled umbrella.

The problem common to all modelling, though, is the quality of the source data. “Garbage In Garbage Out” data uncertainties are crucial, though they do depend on the model. For instance, for an aggregate model at US County level using occupancy and high-level construction type, it is hardly necessary to know the longitude/latitude or the roof geometry as the model is insensitive to these attributes of a property. Arguably the issue with data is the sensitivity of the model output to the granularity (precision) and accuracy of the data. We currently lack methodologies to deal with these uncertainties.

APPENDIX G REFERENCES

The following were referenced in this document:

- Sampling Strategies and Convergence = OasisSamplingStrategiesAndConvergence_v1.
- Sub-models = OasisSubModelsR1.5.
- Data Interfaces specification = OasisDataInterfacesR1.5.
- Output specification = OasisOutputsR1.5.