Colin C. Caprani

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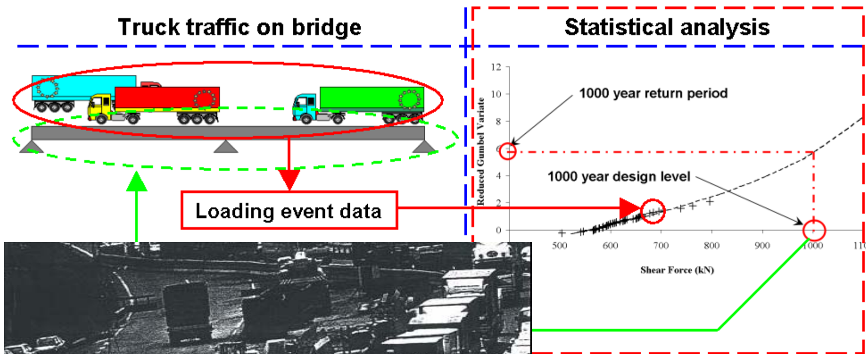

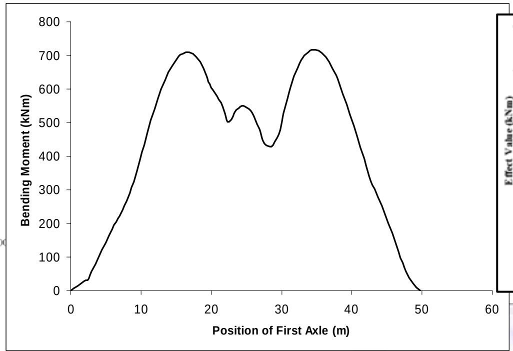

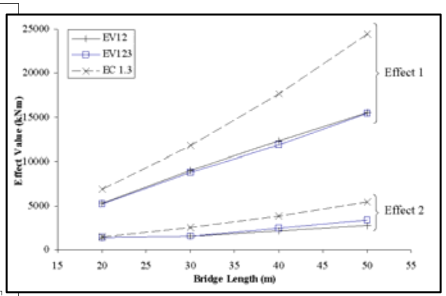

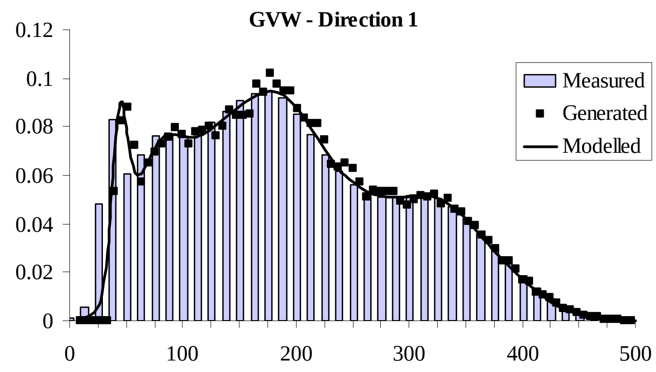

Probabalistic Analysis of Highway Bridge Loading Events

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<u>Objective & Focus:</u>

"To develop better methods of calculating the characteristic static load effect that a bridge may be subjected to."

The project concerns uni- and bi-directional 2-lane short to medium span bridges

Many forms of load effect, such as bending moments & shear are studied

<u>Applications:</u>

1. Assessment of existing bridge structures

2. Statistical framework for the derivation of statistical dynamic amplification factors for trucks on bridges

3. Potential for the statistical methods developed to be used in

- **wind speed analysis**
- **rainfall analysis**
- **wave height analysis**

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Primary Application - Bridge Assessment

- Countries with ageing & decaying bridge stocks spend €m's on bridge repair annually

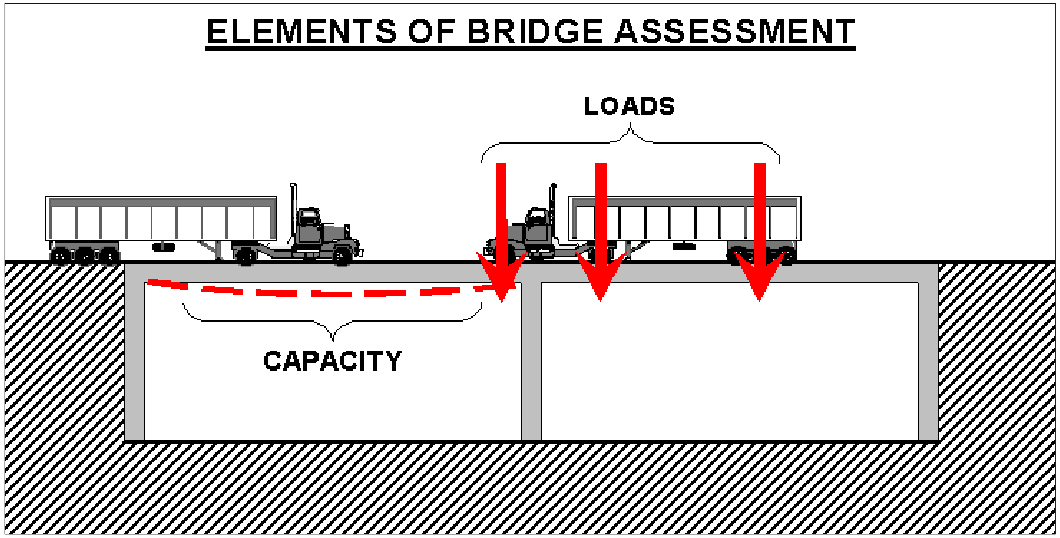
- Bridge rehabilitation/replacement is costly & very disruptive

- Accurate assessment of the structure potentially saves €m's

- The assessment of bridge capacity is relatively accurate

- Load assessment is difficult & inherently less accurate due to the large variation in traffic

- EU suggestions of 48t trucks renders this very important



Conclusion: There are large potential savings with accurate methods of load assessment

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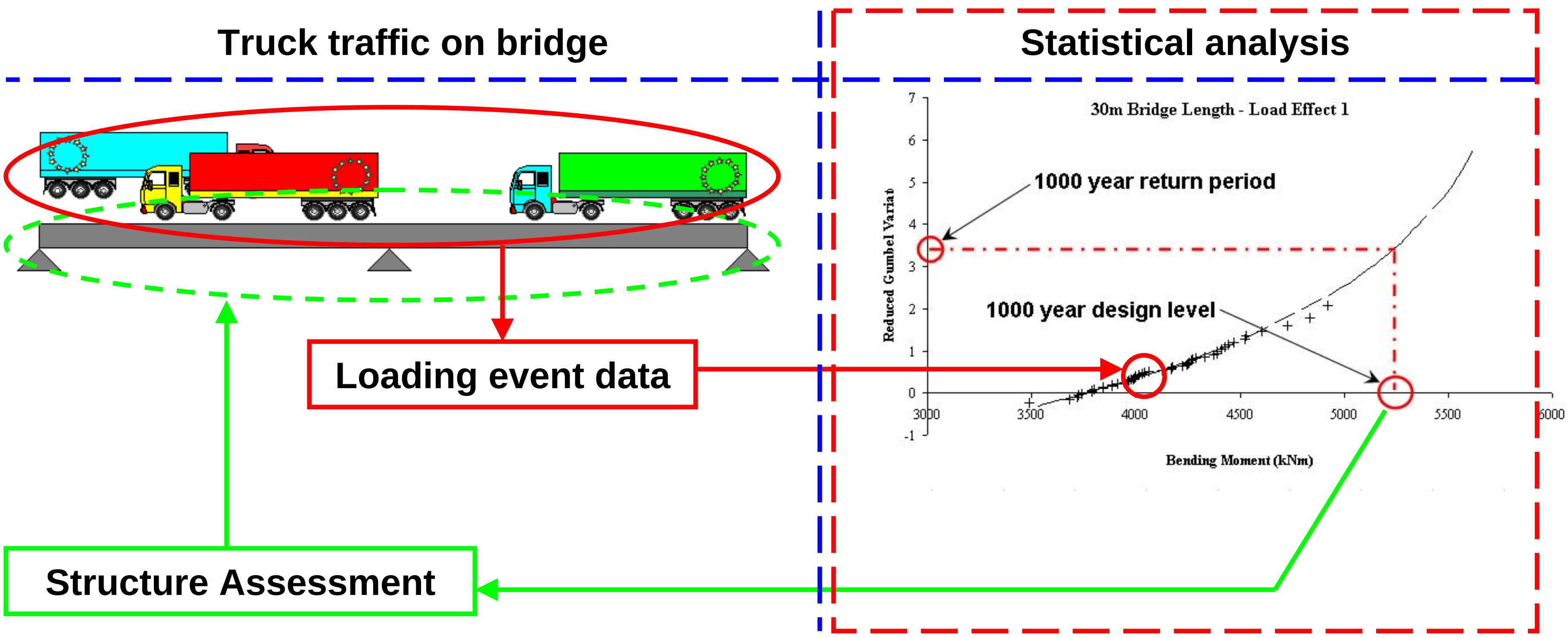
Flow chart description of project & primary application

Represents this project's area of interest



Traffic is generated using Monte Carlo simulation from Weigh-In-Motion data

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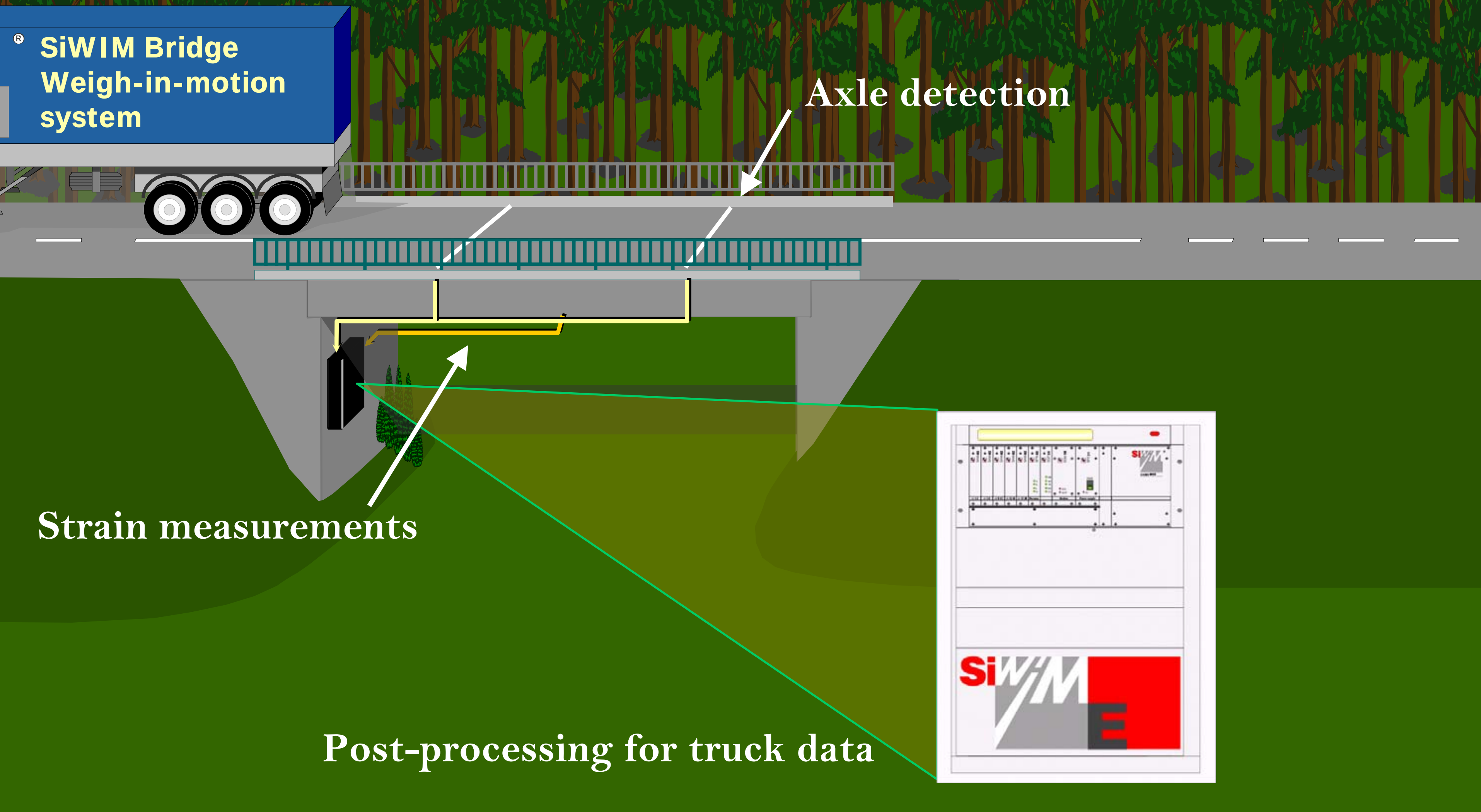
Weigh-in-Motion (WIM) was used to collect statistics on truck weights, etc.



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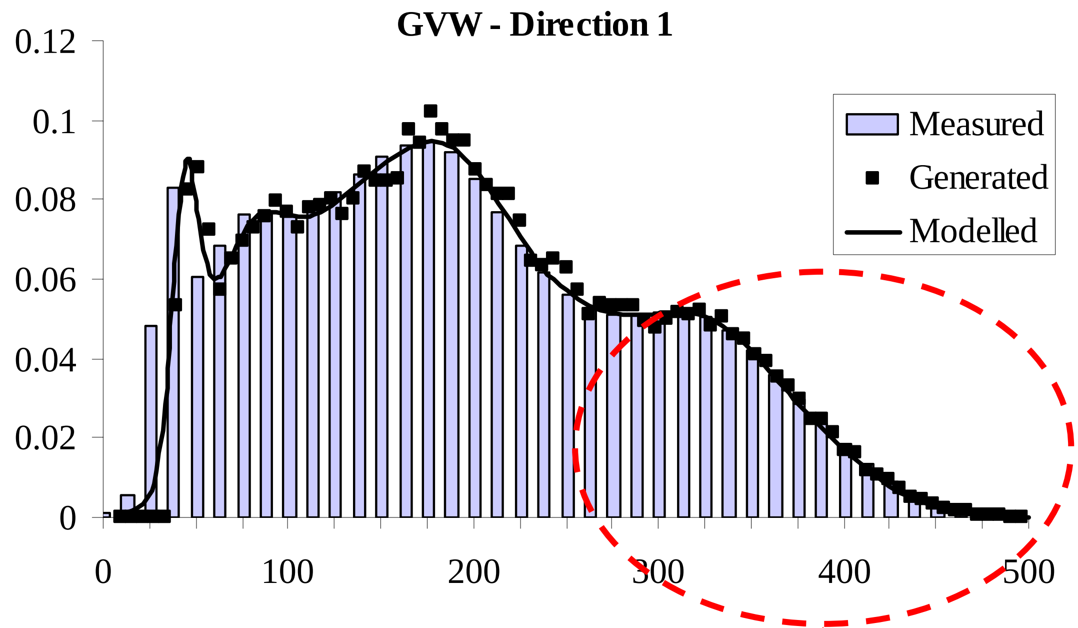
Generation of truck traffic:

Generally only short periods of live measured truck data is available

1-2 weeks is industry standard

Statistical distributions are fitted to this data (modelled distribution)

Long periods of truck traffic are randomly generated from these distributions



Example shown:

- Site:	RN10, Angers, France
- Measurement Period:	7 days – 17,218 trucks
- Modelled Period:	1 year (250 working days)
	– about 825,000 trucks

Increased accuracy in the tail results from the data fitting operation

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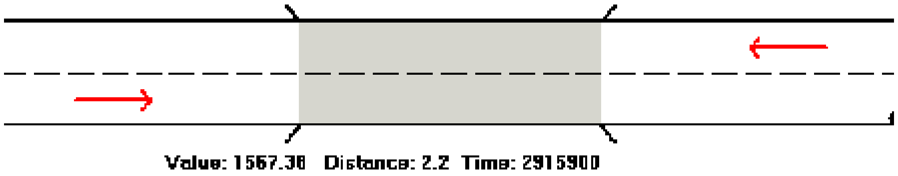
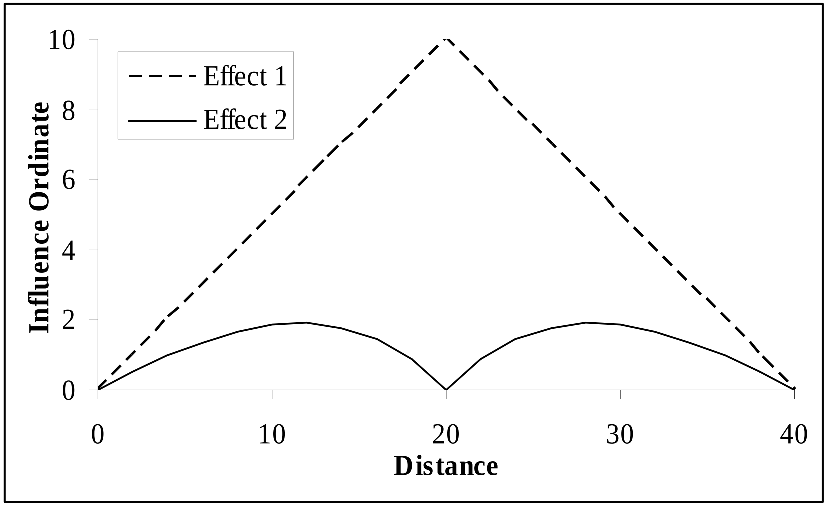
Determination of Bridge Response to the Passage of Trucks:

Influence lines for BM, V, give the load effect of truck presence events

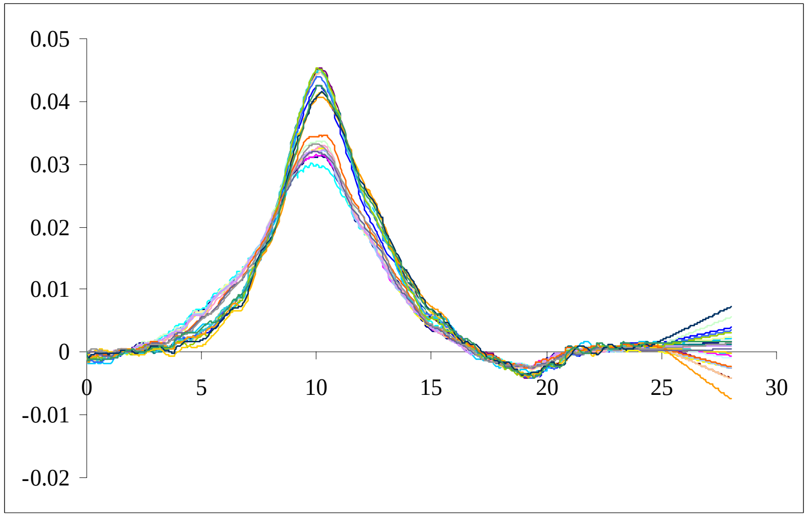


Theoretical influences lines can be used:



Study for CivilComp 2002 - Prague

Or measured influence lines can be used:



Research Grant: Bridge B224, Vienna

Each event and associated effect is recorded for further statistical anaylsis

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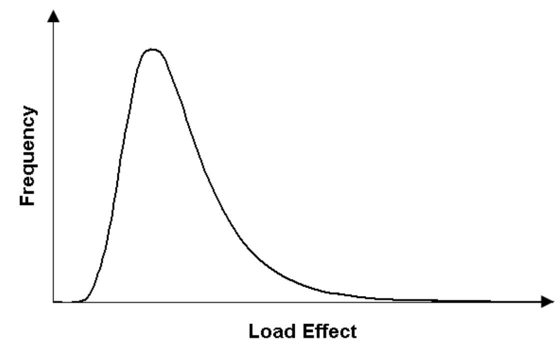
<u>Statistical Analysis:</u>

- The load effects noted each day form a statistical distribution

- The maximum load effect of each day form another distribution

    - these effects meet stationarity requirements (only daily cyclical variations are taken into account)

    - thus they are of an extreme value distribution form



- When plotted, the maximum daily load effect values should conform to the Generalized Extreme Value distribution

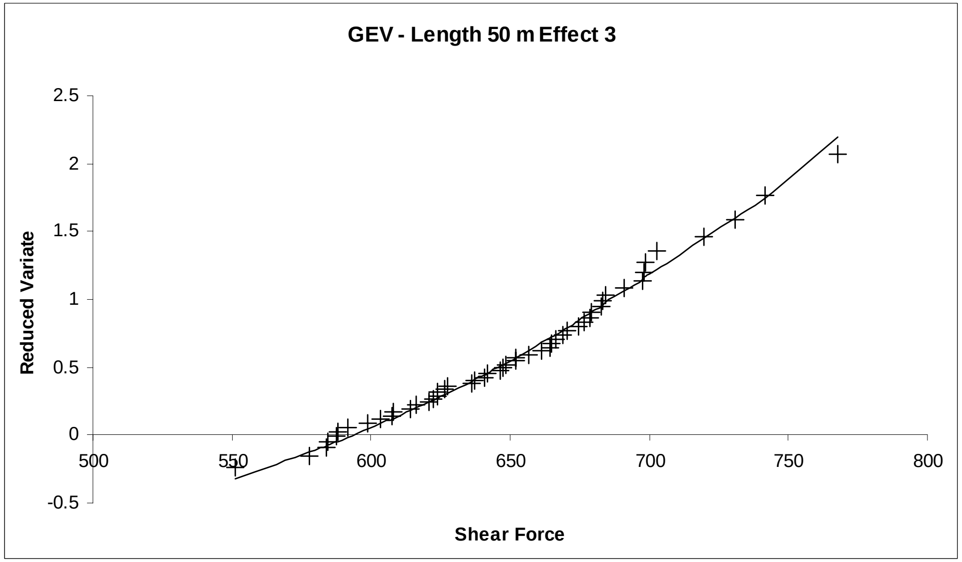
$$G(z) = \exp\left\{ -\left[1 + \xi \left(\frac{z-\mu}{\sigma} \right) \right]^{-1/\xi} \right\}$$

- Each event must also be independent and identically distributed (iid)

- This means that the same statistical mechanism generated all the events

Data & GEV plotted on Gumbel probability paper

<u>Note:</u> Reasonable fit



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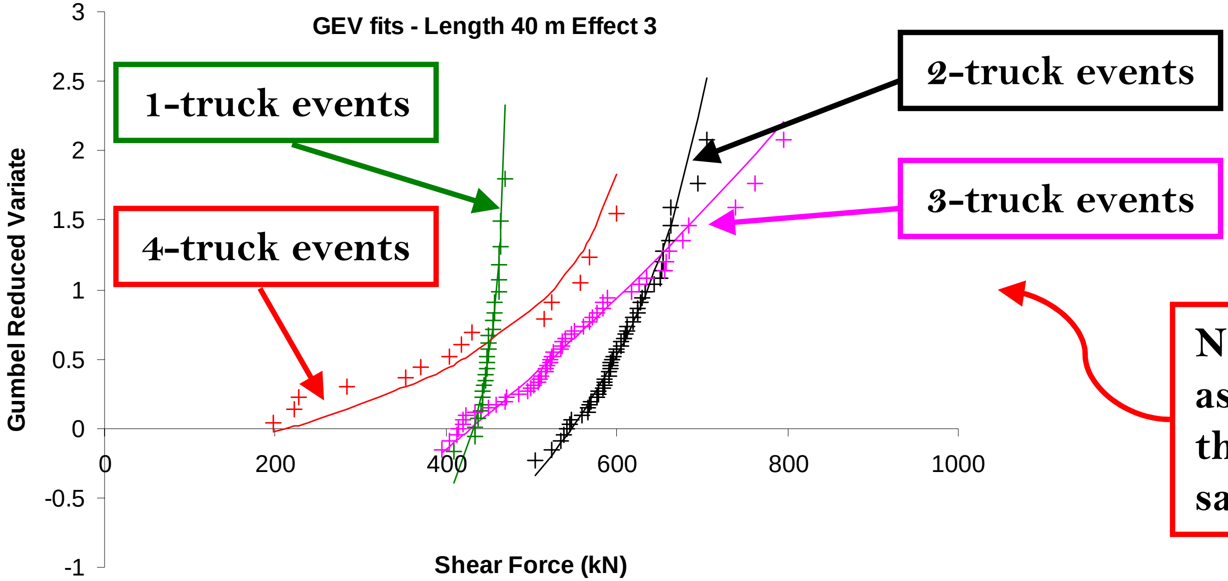
<u>Further Statistical Analysis:</u>

- Subsequent examination revealed the iid assumtion to be incorrect

- Truck event statistics depends on the number of trucks comprising the event:



Note that if the iid assumtion were correct, these plots would be all the same – clearly not so

Thus a new type of analysis was required…

Literature reviews of the statistical analysis of extreme wind speeds revealed similarites:

- 2-truck events ∝ thunderstorms   - 3-truck events ∝ hurricanes

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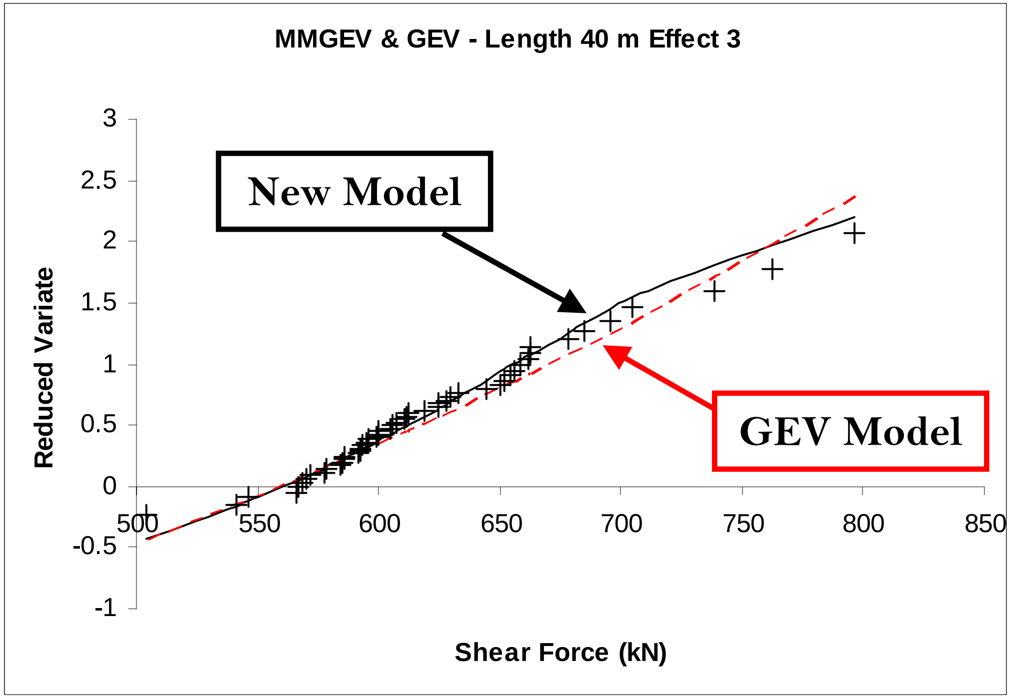
Mixed Mechanism Statistics:

The theory of Gomes & Vickery for extreme wind speeds in mixed climates was adopted:

$$MMG(z) = \prod_{i=1}^{n} G_i(z) = \exp[-f(z)]$$

$$f(z) = \sum_{i=1}^{n} \left[1 + \xi_i \left(\frac{z-\mu_i}{\sigma_i}\right)\right]^{-1/\xi_i}$$



Thus each event-type is analysed seperately & then combined for the compostite distribution

The iid assumption is now met

Note also the double curvature of the new model which tends to fit the data better

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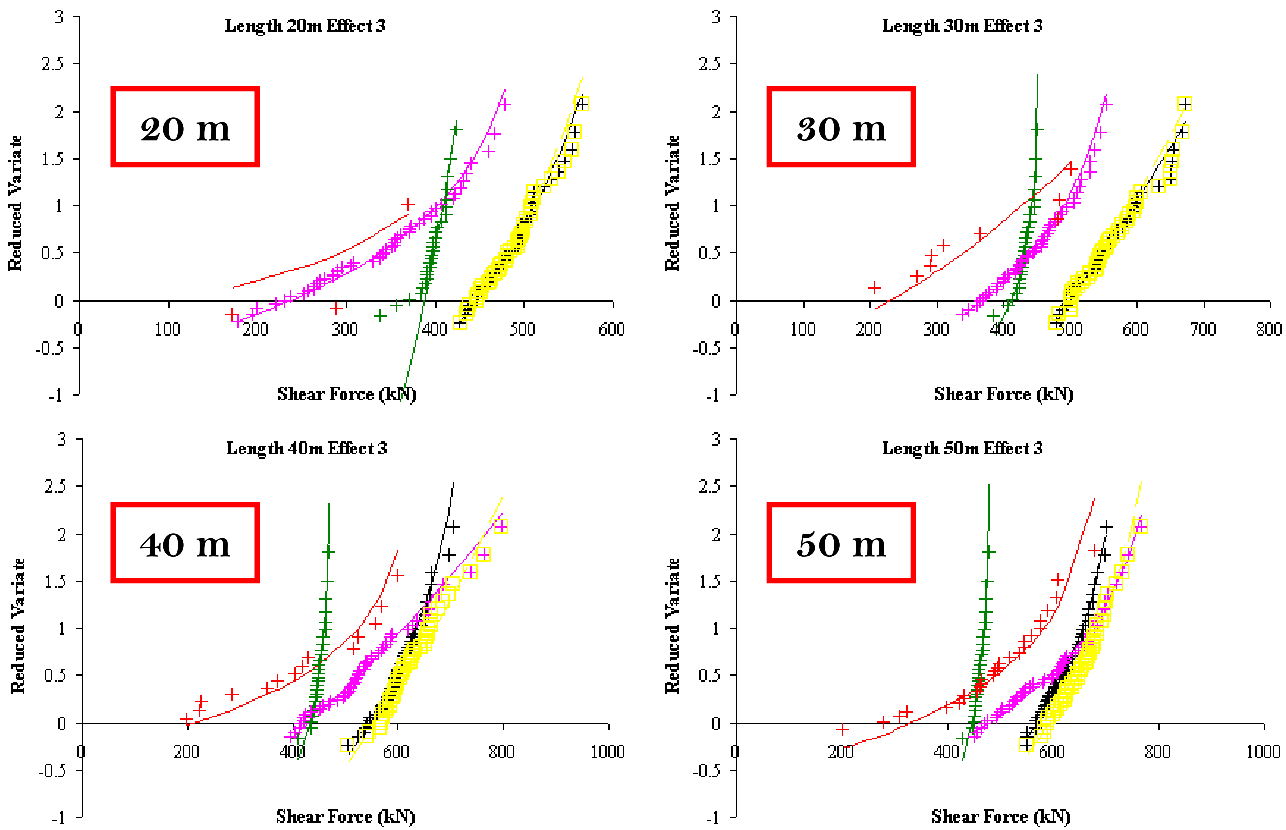
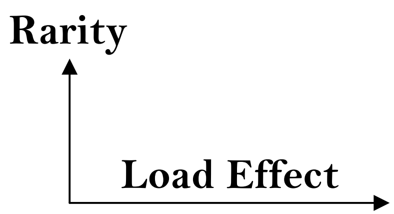
Mixed Mechanism Statistics:

Sample graphs are given below

- Note 3-truck events become important as the bridge length increases

- Single and 4-truck events are not evidently critical





1-truck events

2-truck events

3-truck events

4-truck events

MM fit

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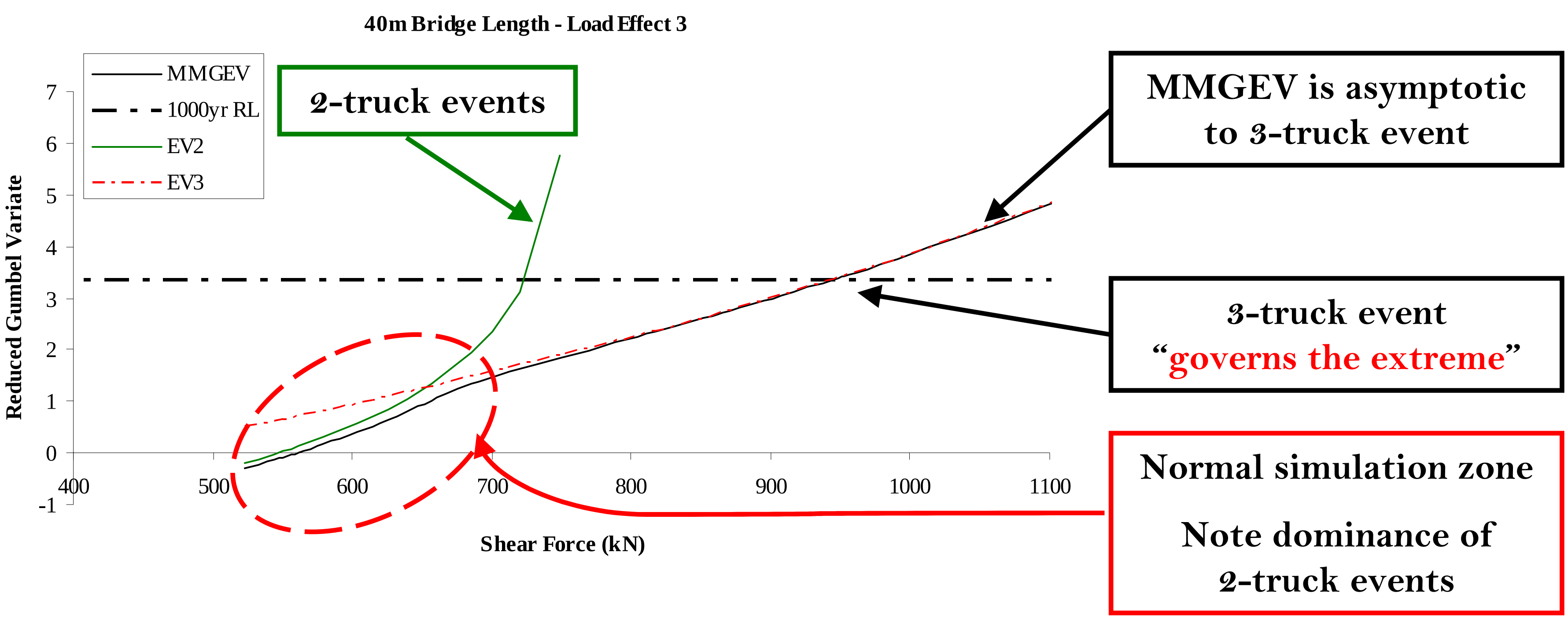
Mixed Mechanism Statistics:

Removing the data and non-essential curves for clarity & extending the axes:



New model shows that 3-truck events are very important in short to medium span bridges - this had been the subject of doubt

Note that the graphs curve upwards – there is a physical limit to the load effect

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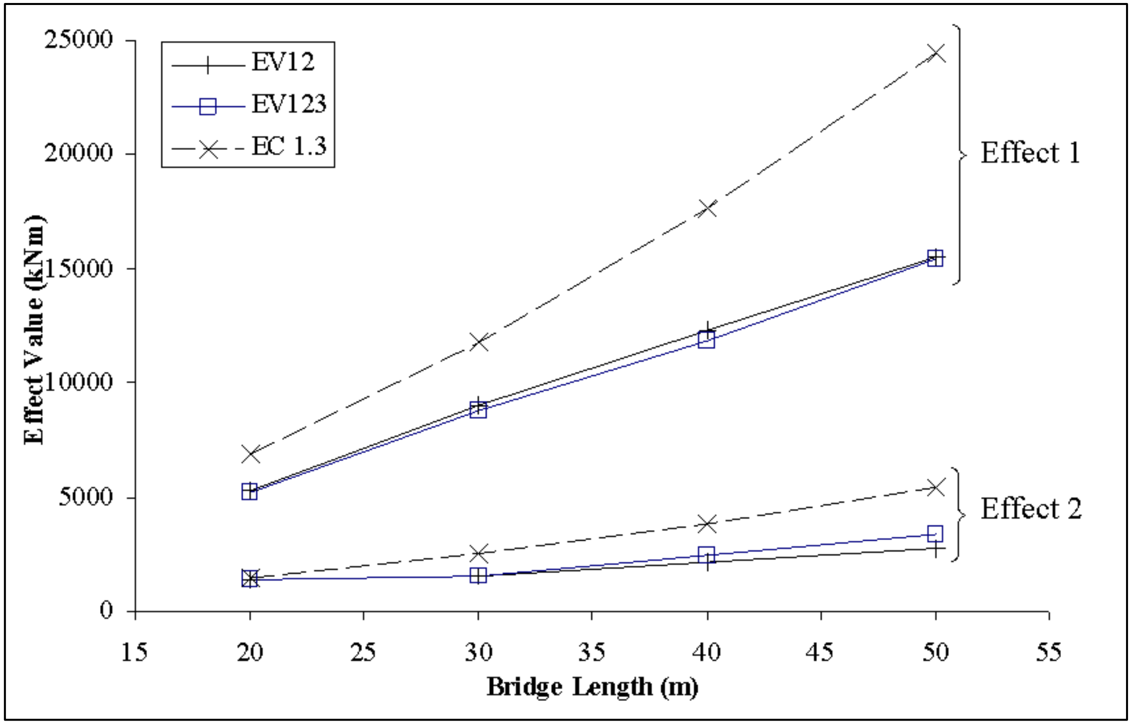
Comparison with design code:

For 1- & 2-truck events (EV12) and 1-, 2- & 3-truck events (EV123) typical comparisons with a design code (Eurocode 1.3) are:



It is clear to see that the design code is very conservative
- as it has to be

Further, the potential savings from site-specific load assessment can be gauged

Also the different behaviour between the two effects can only be attributed to the shape of the influence line

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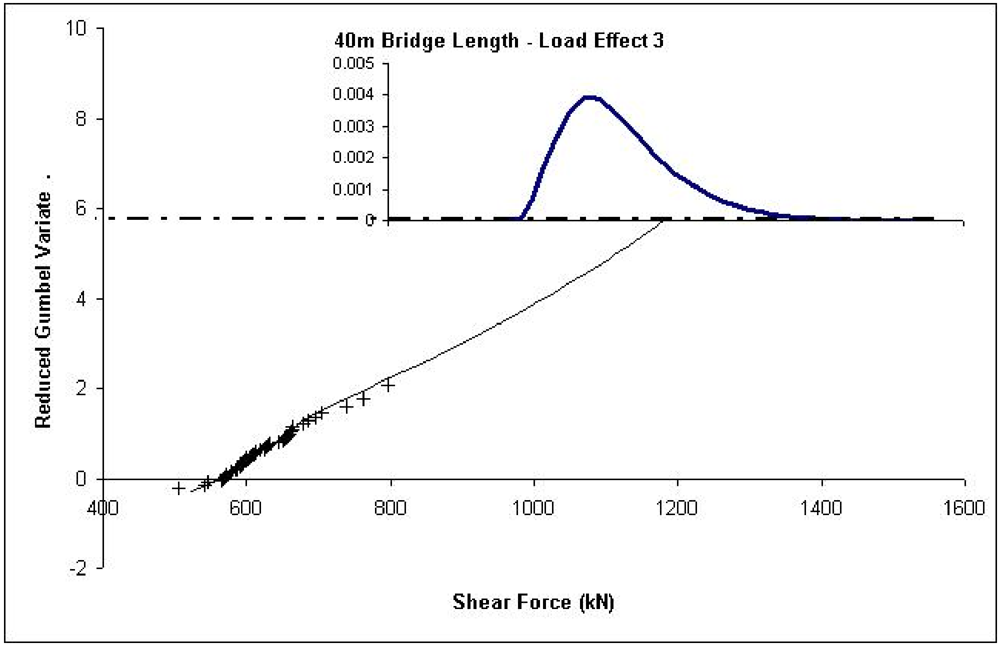
Variability of extrapolated extreme:

If the procedure was repeated we would get similar but different results

If we did this many times we could form a distribution of the characteristic value

It is usual to assume a Normal shape for this distribution



This "full" process is not required - can use an alternate method based on statistical likelihood

Predictive Likelihood can be used to obtain the distribution directly

This method assesses the "relative credibility" of one predictant against another

Variation of the parameter values as well as the inherent variation is accounted for

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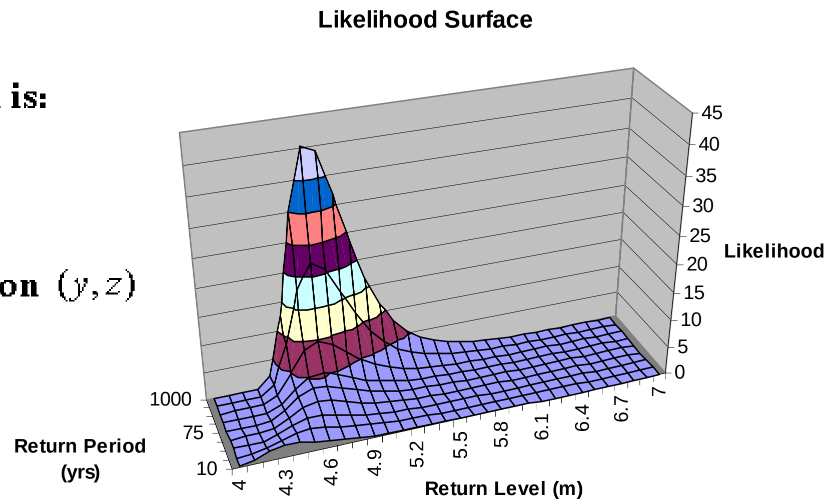
Predictive Likelihood:

The relative support of the predictand, given the data is:

$$L_p^*(z|y) = \frac{L_p(z|y)}{\sqrt{|I^z(\hat{\theta}_z)|}} \left\| \frac{\partial\hat{\theta}}{\partial\hat{\theta}_z} \right\|$$

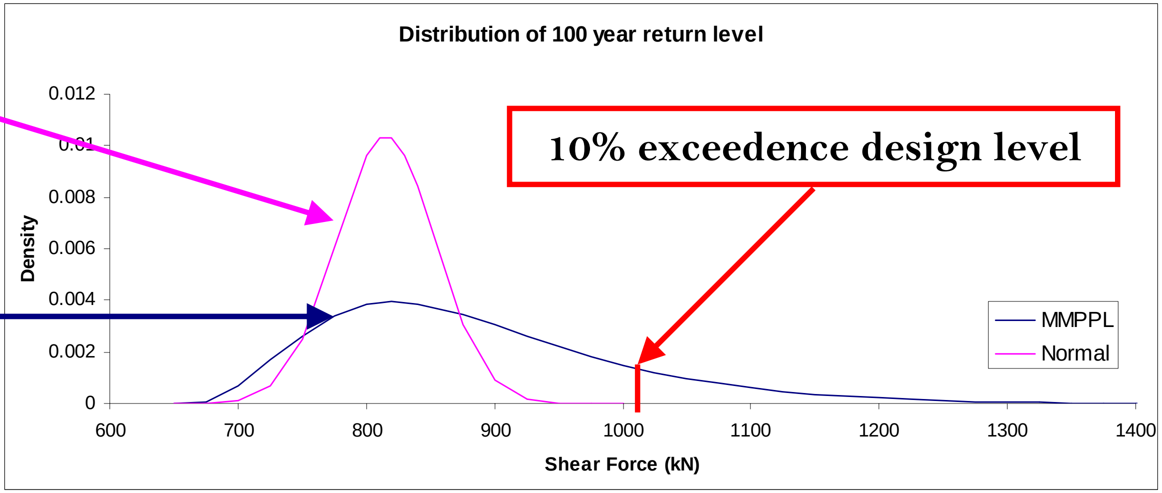
$I^z(\hat{\theta}_z)$ **is the observed information matrix of** L_p **based on** (y, z)

$$L_p(z|y) = k(y)\sup_\theta f(y;\theta)g(z;\theta)$$



Normal Approximation via “delta method”

Mixed Mechanism Profile Predictive Likelihood – highly skewed



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Summary:

1. The iid assumtion does not hold for composite truck events

2. Truck event modelling requires mixed-mechanism statistics

3. 3-truck events must be modelled in the assessment of 20-50 m length bridges

4. Most load effects show an upper physical bound to their maximum value

5. Preditive likelihood demonstrates the skewed distribution of predicted extremes

6. Significant savings are shown possible whilst using site-specific load assessment

7. Mixed mechanism predictive likelihood may be used in other fields such as:
    - extreme wind speed analysis
    - extreme rainfall analysis
    - extreme wave height analysis

Acknowledgment

My sincere gratitude to Prof. Eugene O'Brien for his endless patience & expertise