

Calibrating Road Design Guides Using Risk-Based Reliability Analysis: A Case study



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Outline

- ❑ Introduction
- ❑ Methodology
- ❑ Case Study
- ❑ Results & Discussions
- ❑ Future Directions

Introduction

- ❑ In highway geometric design, most design inputs & model parameters include considerable uncertainty
- ❑ How existing design guides account for such uncertainty?
 - ❖ By provide a deterministic approach for design requirements using conservative percentile values for design inputs
- ❑ That deterministic approach has two main shortcomings:
 - ❖ The selection of the percentile values is not based on definitive safety measures
 - ❖ There is little knowledge on the safety implications of deviating from the design standards

Introduction

- ❑ One approach that has been advocated to account for this uncertainty is reliability analysis
- ❑ In reliability analysis, the design variables are treated as random variables (expressed as probability distributions)
- ❑ This study proposes an important application of reliability analysis: Calibration of geometric design models to yield consistent & adequate safety levels

Introduction

- The proposed calibration process will enable design guides to provide new design criteria that:
 - ❖ are consistent in terms of the risk level
 - ❖ are better reflects the stochastic nature of design inputs
 - ❖ help designers to estimate the safety implications of deviation from standard designs

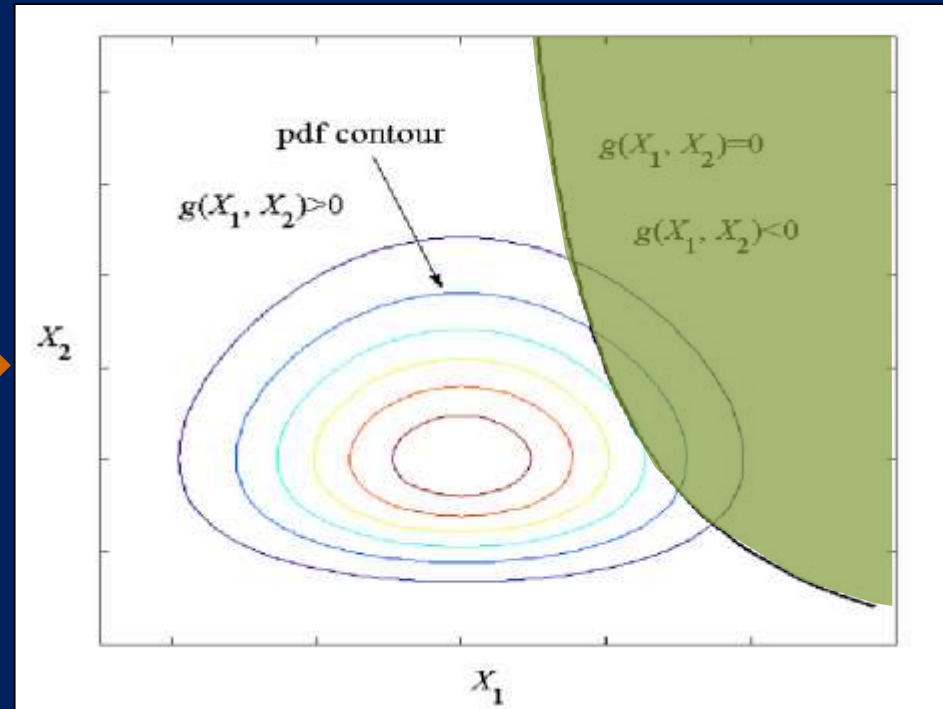
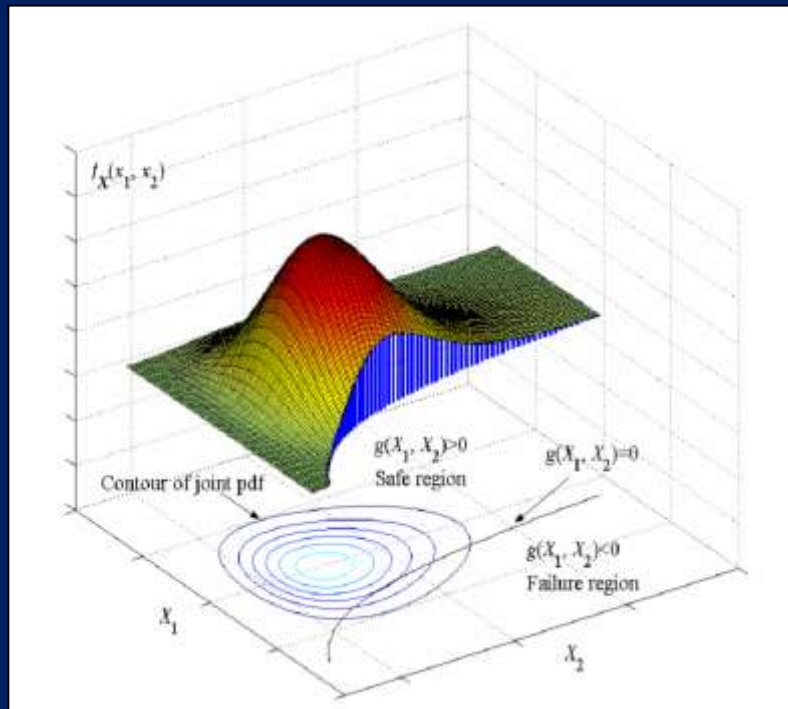
Methodology

- ❑ Reliability usually refers to the complement of the failure probability or the Probability of non-compliance (P_{nc})
- ❑ The main task in reliability analysis is the calculation of the (P_{nc})
- ❑ The first step in determining the (P_{nc}) is to identify a limit state function; $g(x)$; which defines what is considered to be failure

$g(x) \leq 0$: failure (non-compliance)
where x is a vector of random input variables.

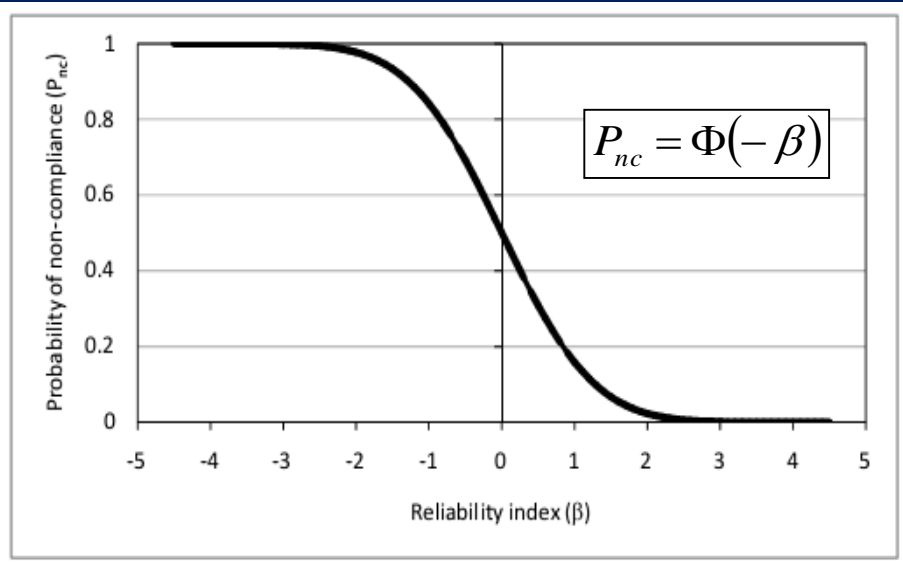
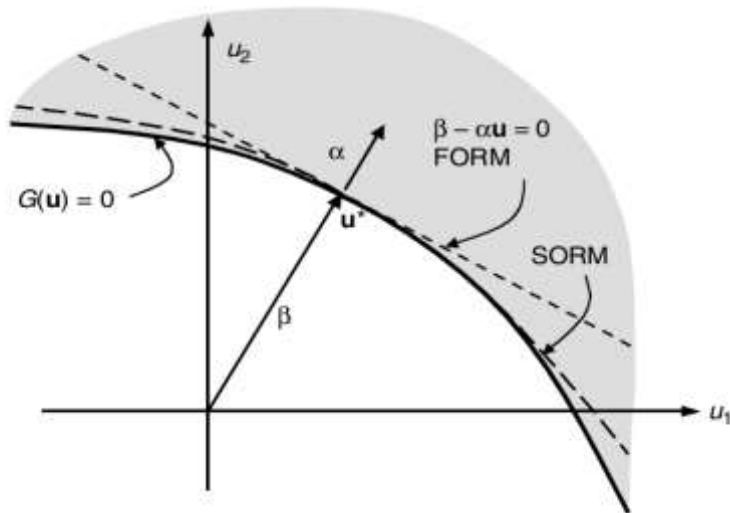
Methodology

- The (P_{nc}) then can be calculated by integrating the joint PDF of random variables; $f(x)$; over the failure region.

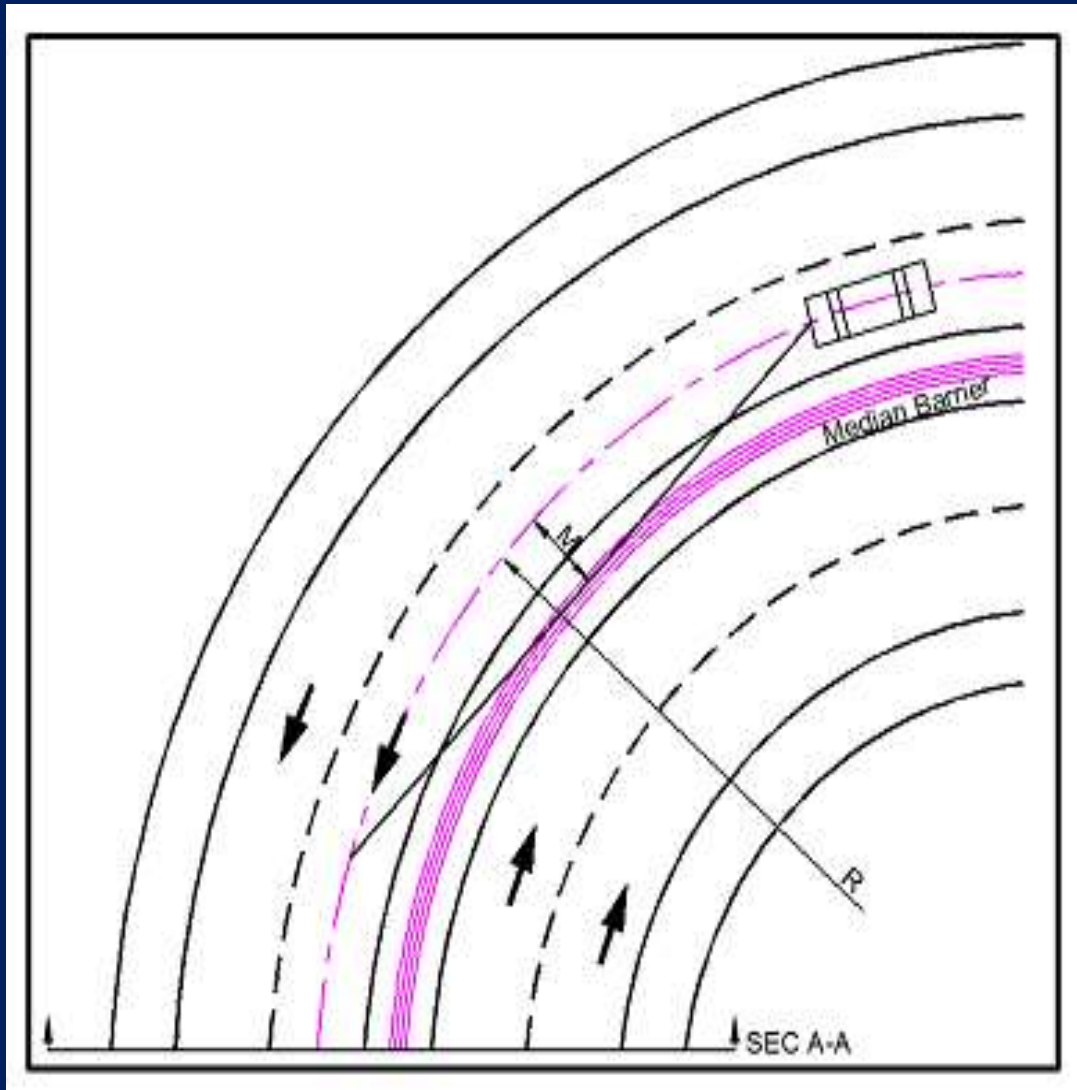


Methodology

- ❑ In most cases there is no analytical method to get an exact solution of the previous integration
- ❑ Many reliability methods are used get an approximate solution of (P_{nc}) including: (MVFOSM), (FORM), (SORM), ... etc.



As a case study,
this study provides
calibrated design
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Case Study

- ❑ In the design case discussed here, non-compliance occurred when the required stopping sight distance (SSD) equals or exceeds the available sight distance for the driver (ASD)
- ❑ Limit state function $g(x)$ is defined as:

$$g(x) = \{ ASD - SSD \}$$

$$g(x) = \left\{ \left[2 \times R \times \cos^{-1} \left(1 - \frac{M}{R} \right) \right] - \left[(V \times PRT) + \frac{V^2}{2(a + gl)} \right] \right\}$$

Design variables considered

Parameter	Mean	Standard Deviation	Distribution	Value Used for Design
Perception and reaction time	1.5 sec	0.4 sec	Log normal	2.5 sec
Driver deceleration	4.2 m/sec ²	0.6 m/sec ²	Normal	3.4 m/sec ²
Speed	*****			

Design variables considered

□ Two cases were considered regarding to speed:

In the first case:

The operating speed was assumed to be constant and equal to the design speed.

In the second case:

The operating speed was considered as a random variable and was assumed to follow normal distribution.

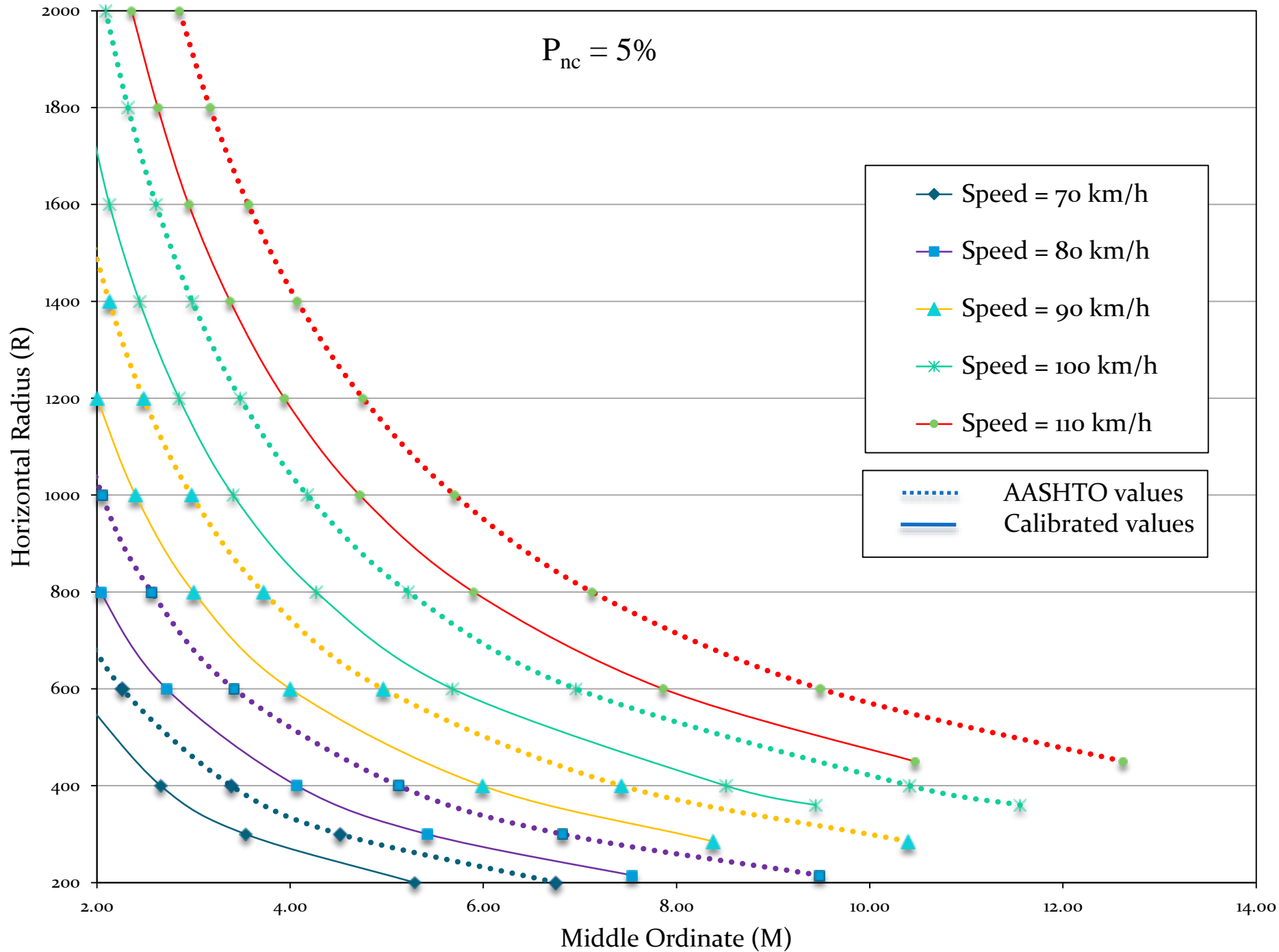
Why Operating Speed?

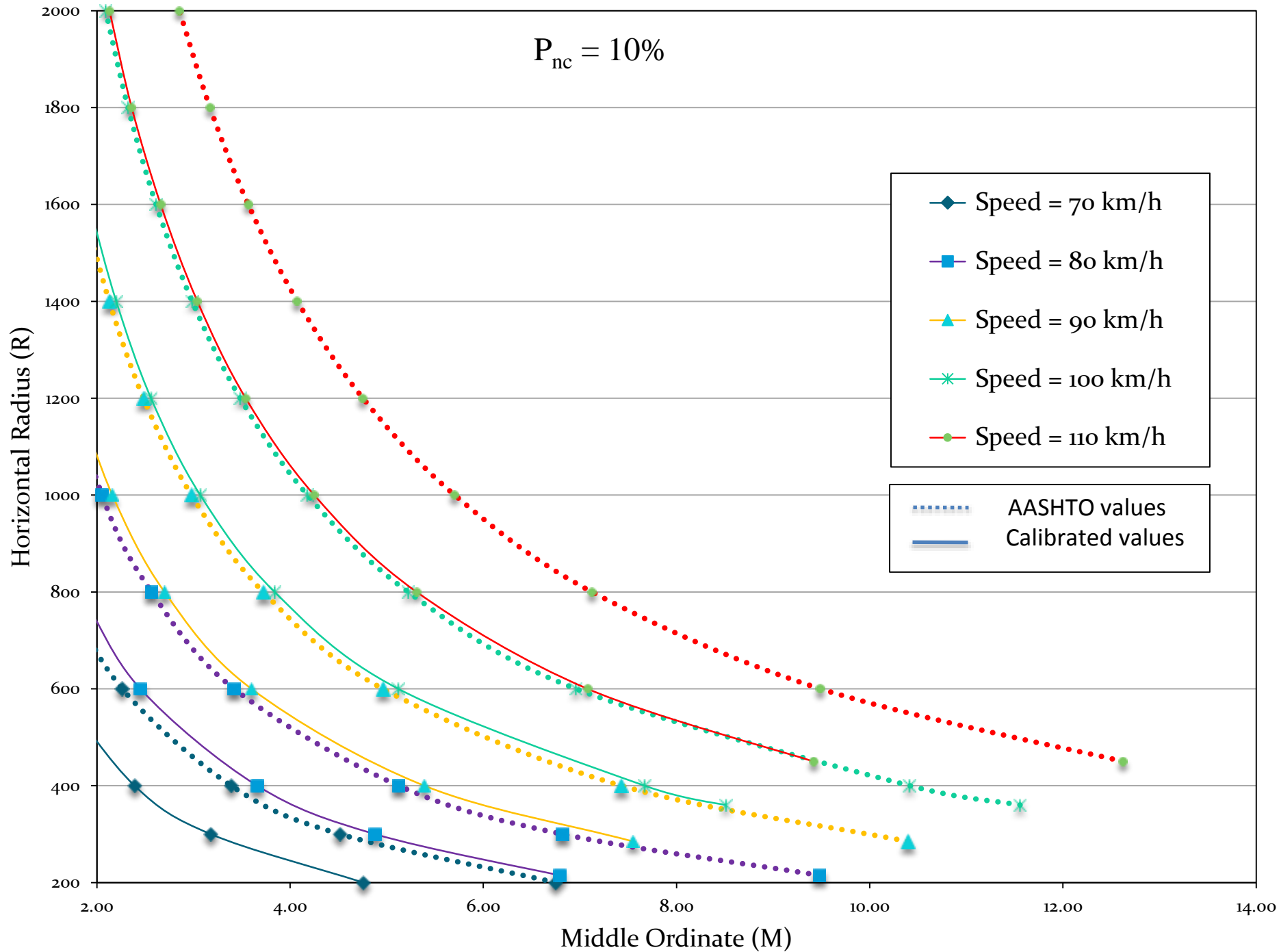
- The operating speed on roadways is highly variable depending on the road element and driver behavior & characteristics.
- The assumption that drivers operate their vehicles at design speed can be challenged.
- Previous studies showed that the 85th percentile operating speeds on highways is significantly different from design speeds

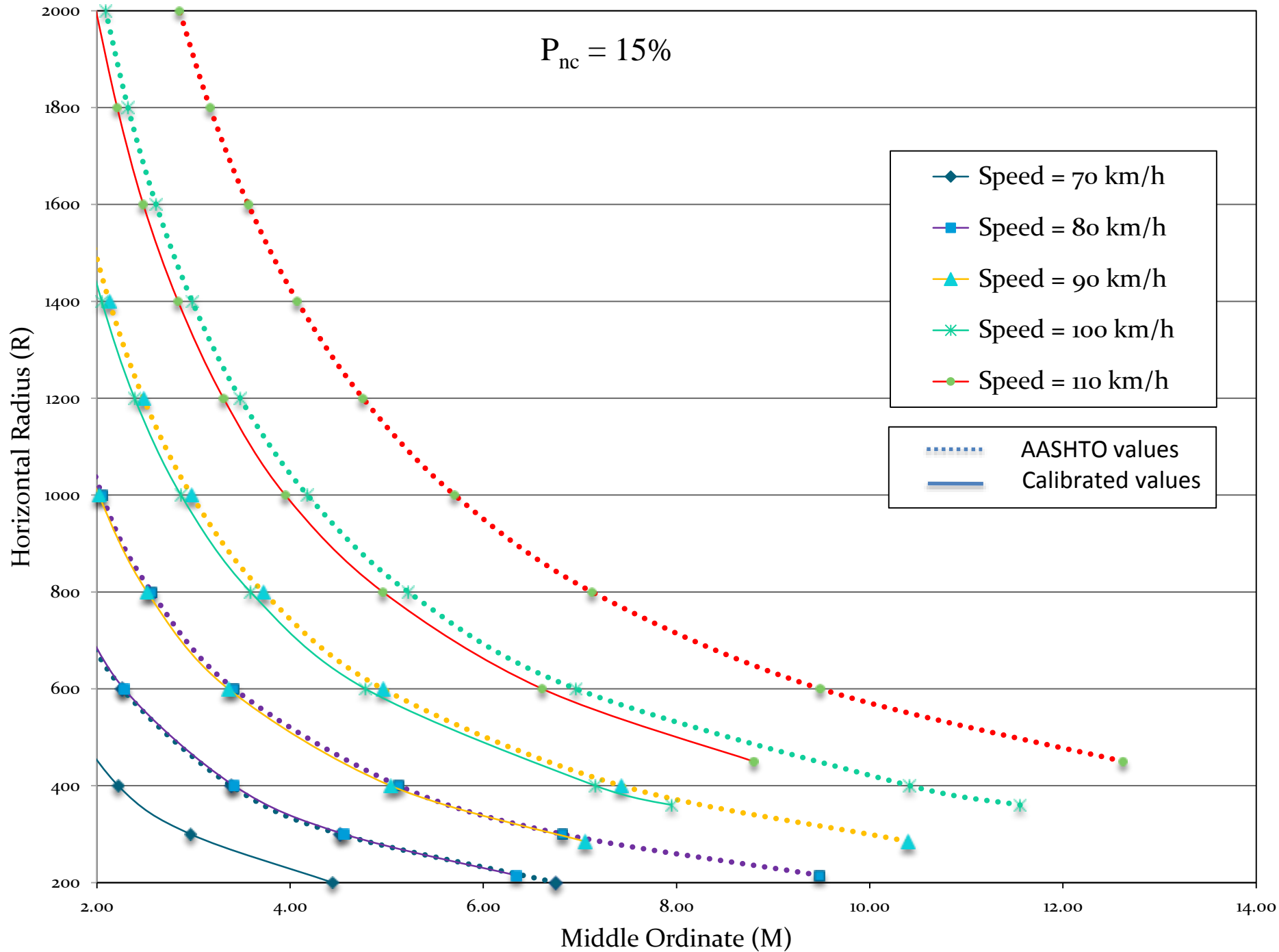
Results and discussion

□ Case 1: Constant operating speed

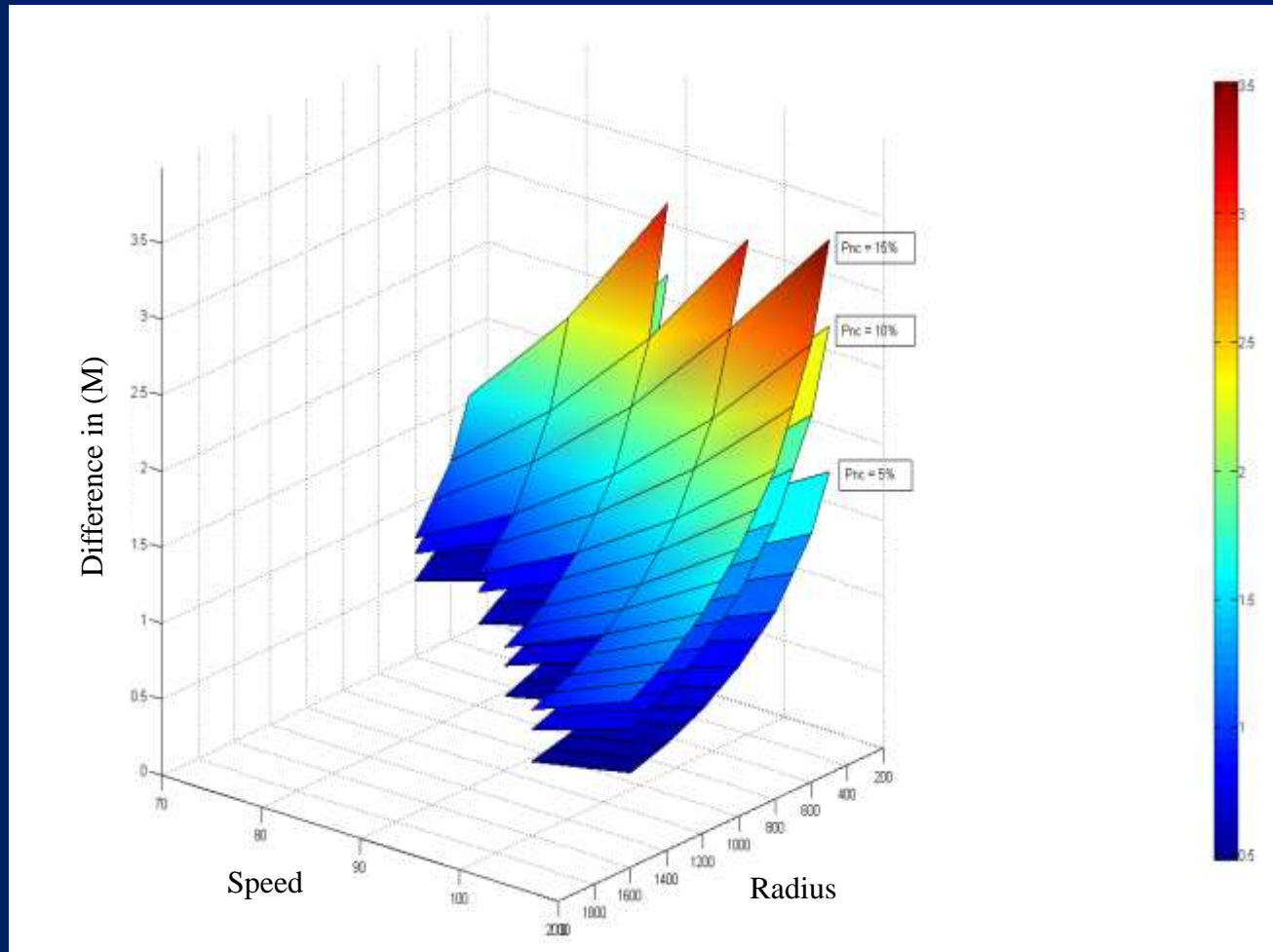
- ❖ Calibration was conducted for a range of values of design speeds (70 to 110 km/h) and curve radii (200 to 2000 m) for three different pre-specified values for the P_{nc} (5%,10% and 15%).







Results and discussion



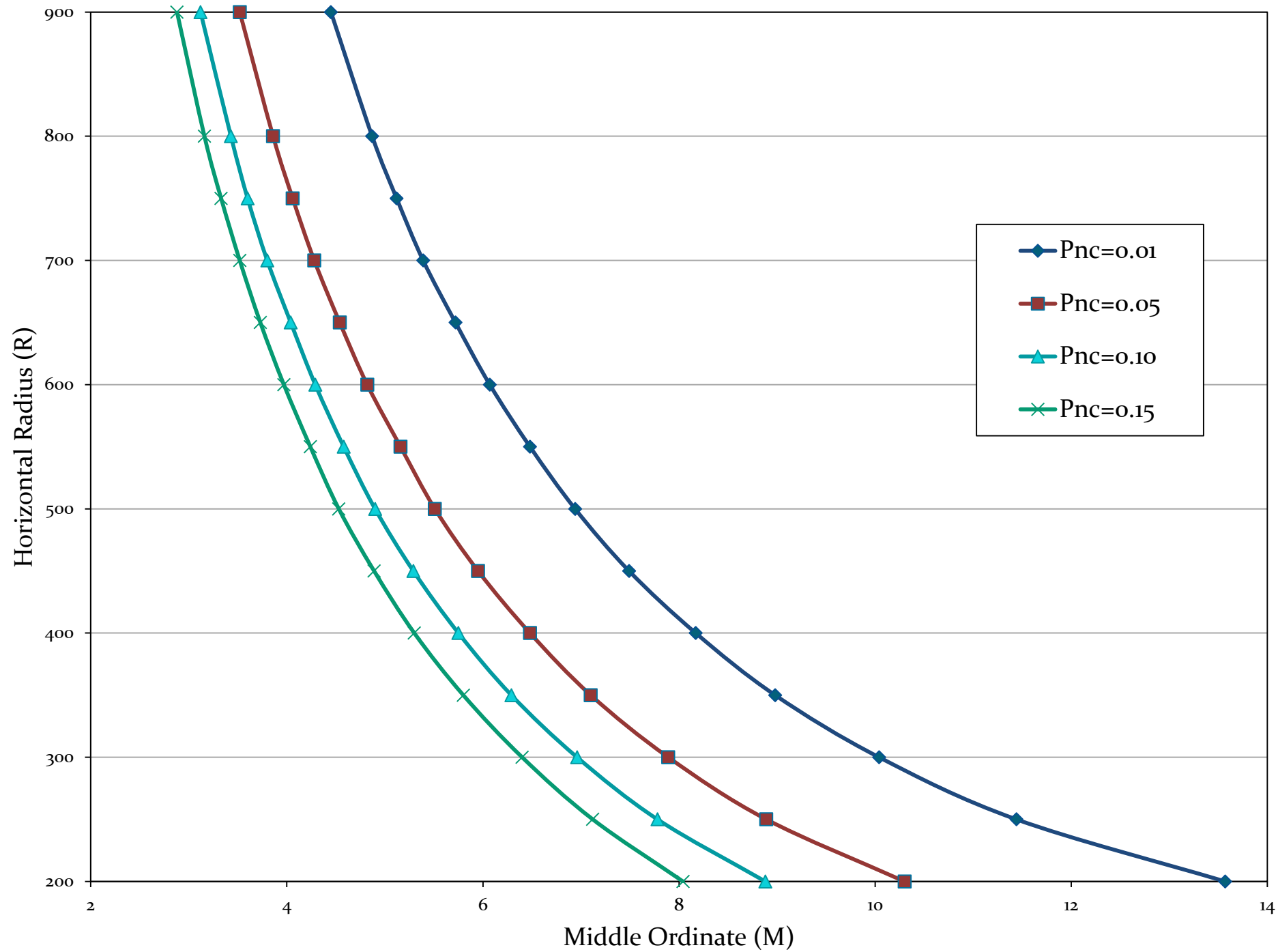
Results and discussion

□ Case 2: Variable operating speed

- ❖ The operating speed was considered as a random variable that follow normal distribution with mean and standard deviation values according to (Richl and Sayed, 2006)
- ❖ Results show that it is important to consider the operating speed in the calibration process as the results vary significantly depending on which speed is used.

Radius	Design speed Range	Mean operating speed	Standard deviation of Operating speed
200	70	80.38	8.119
250	70-80	84.21	6.537
300	70-90	86.78	5.623
350	70-90	88.61	5.094
400	70-100	90.00	4.803
450	70-110	91.09	4.659
500	70-110	91.96	4.598
550	70-110	92.68	4.598
600	70-110	93.28	4.630
650	70-110	93.80	4.687
700	70-110	94.23	4.751
750	70-110	94.62	4.825
800	70-110	94.95	4.898
900	70-110	95.52	5.051

Source: Richl and Sayed, 2006

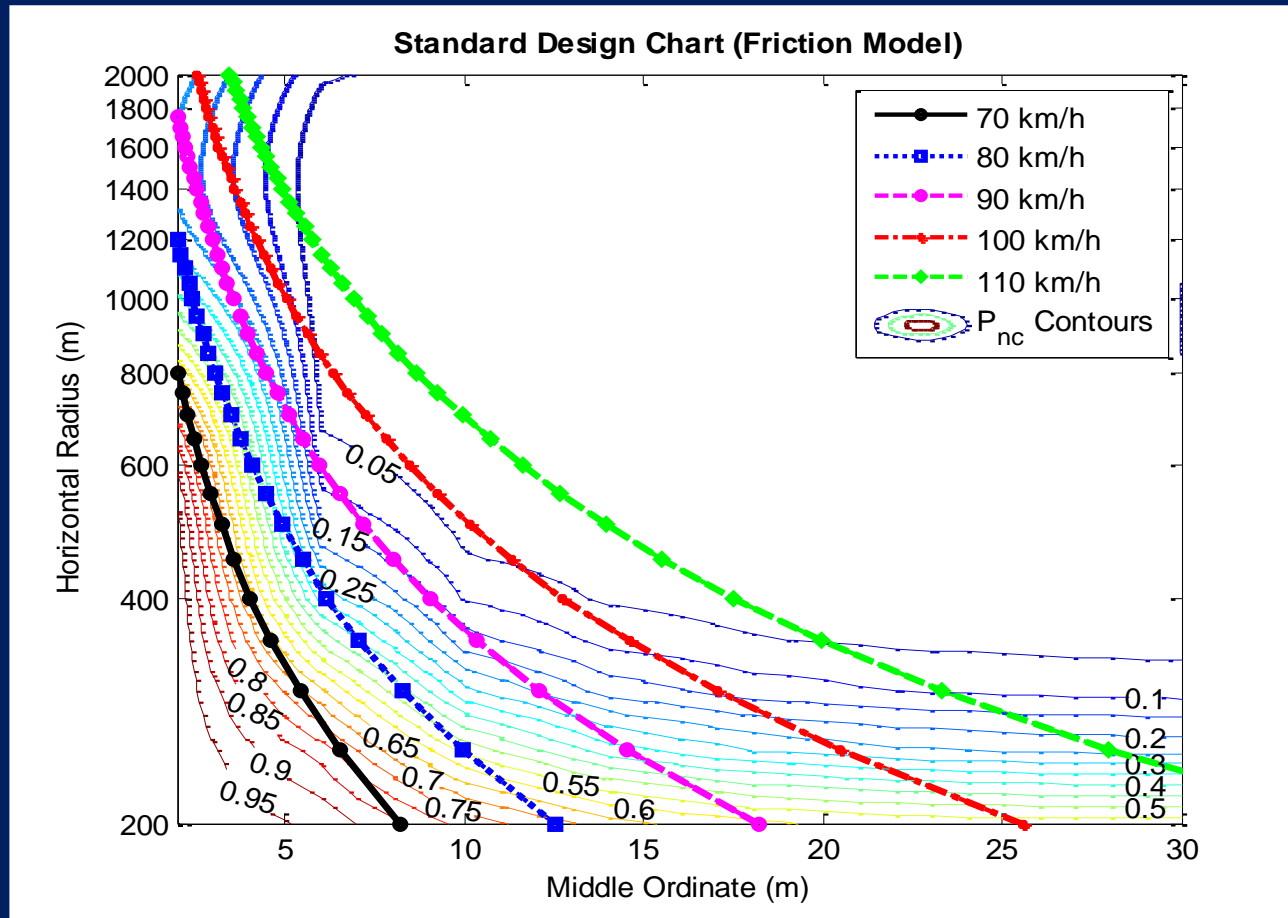


Results and discussion

- Here is an example that show how results are affected by the type of speed used (operating & design speeds)

Radius	Design speed	Mean operating speed	M “using design speed”	M “using operating speed”
200	70	80	4.90	10.3
600	105	93	7.30	4.80

Results and discussion



Source: Ismail and Sayed, 2009

Future Directions

- ❑ Establishing more reliable distributions for the design inputs
- ❑ Developing more accurate speed prediction models that incorporate all geometric elements and consider different highway classes.
- ❑ This study assumed that the input parameters are not correlated. This assumption needs further investigation.
- ❑ System Reliability: Consider more than one mode of failure mechanism (e.g. Sight distance and skidding)

Thank you

Questions?