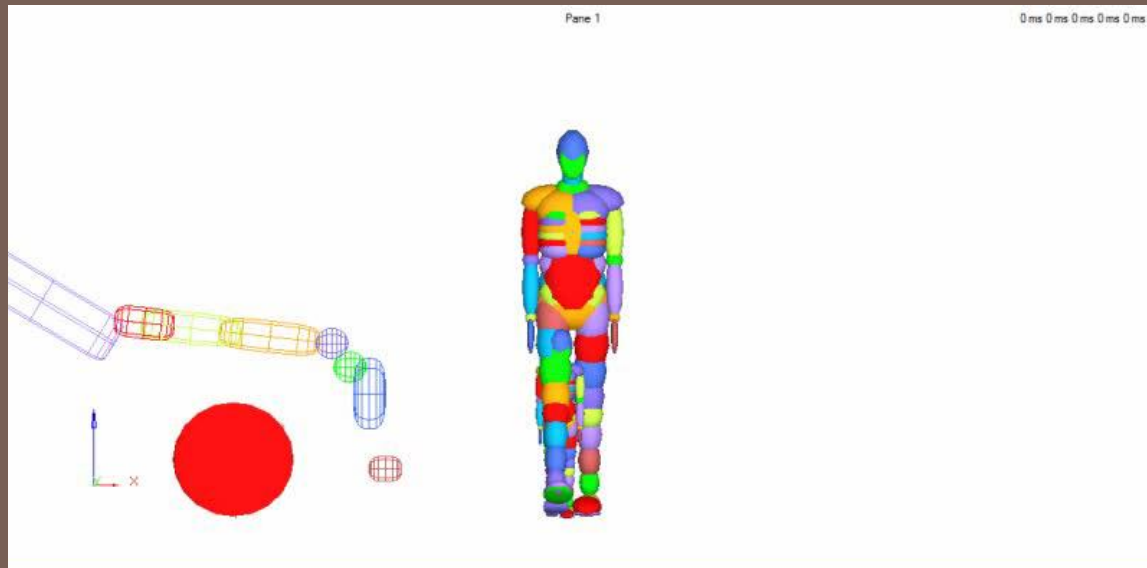

VEHICLE PROFILE OPTIMIZATION TO MINIMIZE THREAT TO PEDESTRIANS

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24/09/2013

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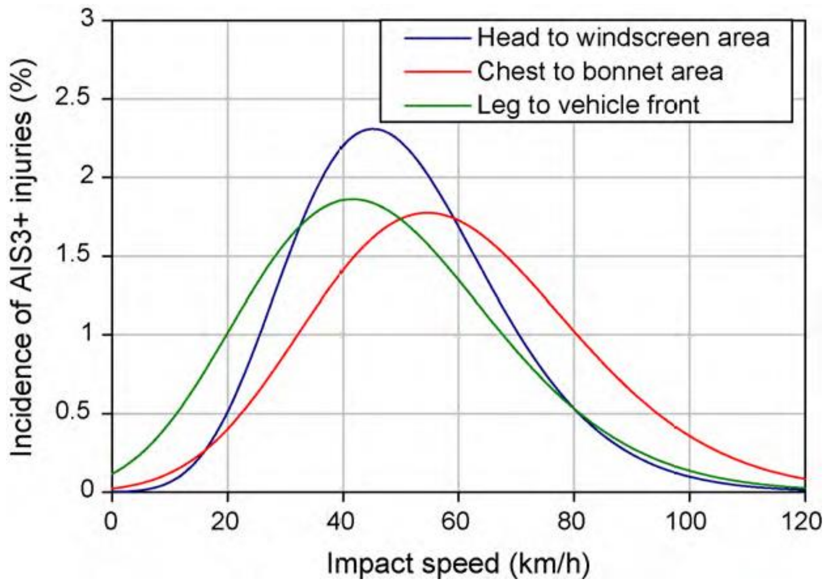
Safety of Vulnerable Road Users - Pedestrians

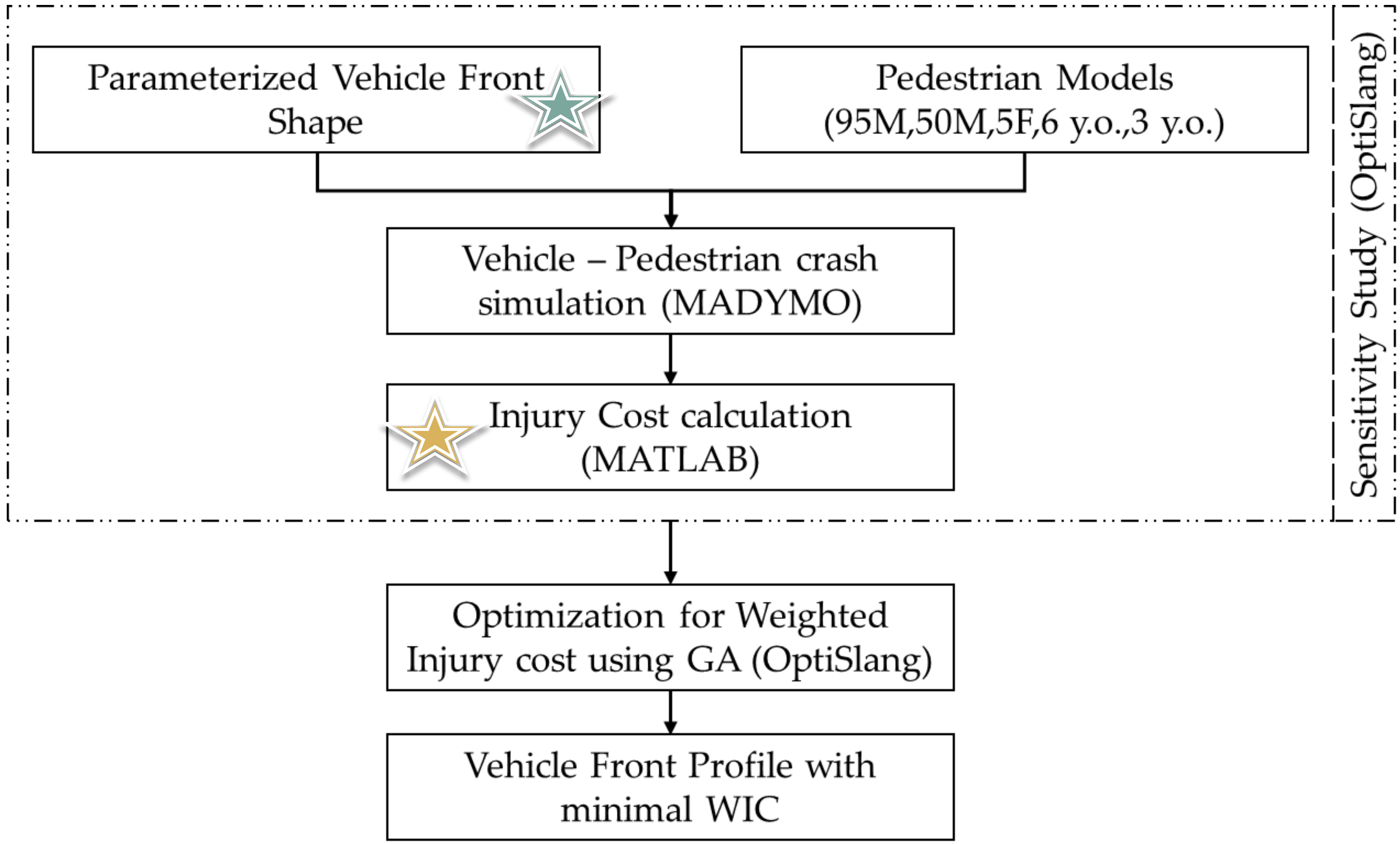
- Vulnerable Road users
  - Bicyclists
  - Motorized two wheelers
  - Pedestrians (least protection)
- "In the majority of crashes, the pedestrian's side is impacted by the front of the car." Yao et. al. 2008
- " For 93% of the collisions of VRU with cars the shapes of the vehicle front were similar to a standard form" – Otte D et. al., 2012



Collision speed of above 40 kmph resulted in more AIS 3+ injuries for kinematic combinations indicated

Fredrikkson R et. al., 2010

Flow chart for Study - OptiSlang



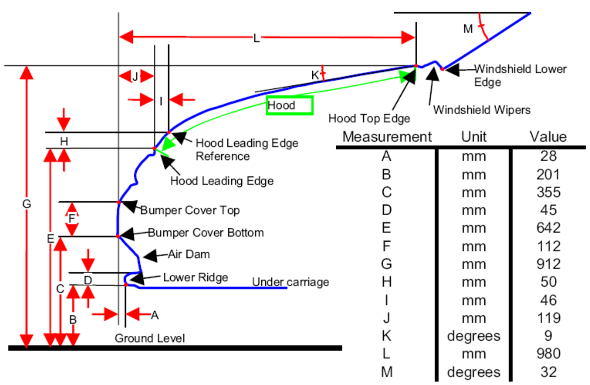
How to model vehicle?

Car photos

Compact* , sedan and SUV – 14 nos.

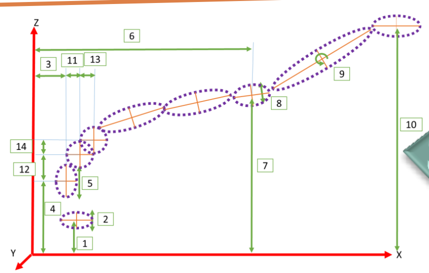
Extract dimensions

Tabulate dimensions



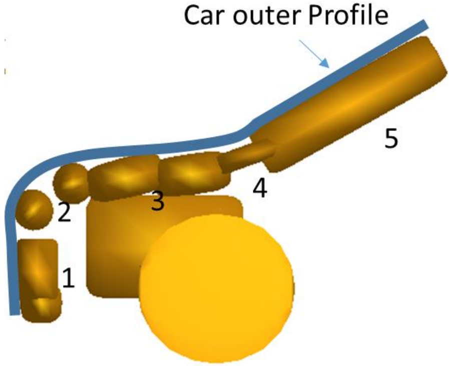
Measurement	Unit	Value
A	mm	28
B	mm	201
C	mm	355
D	mm	45
E	mm	642
F	mm	112
G	mm	912
H	mm	50
I	mm	46
J	mm	119
K	degrees	9
L	mm	980
M	degrees	32

From Kerrigan 2008



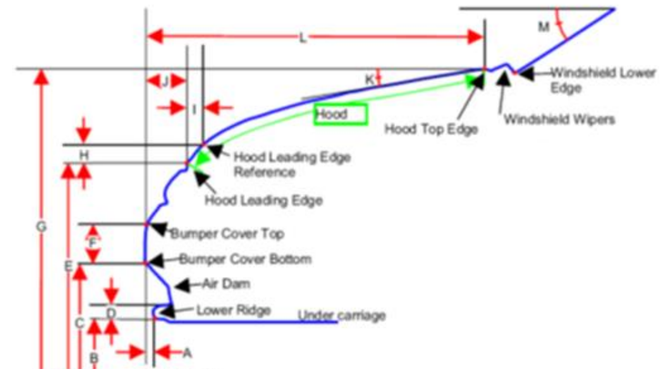
Bumpers (2 Ellipsoids)
Bonnet front (2 Ellipsoids)
Bonnet Middle(2 Ellipsoids)
Bonnet rear (1 Ellipsoid)
Windscreen (1 Ellipsoid)

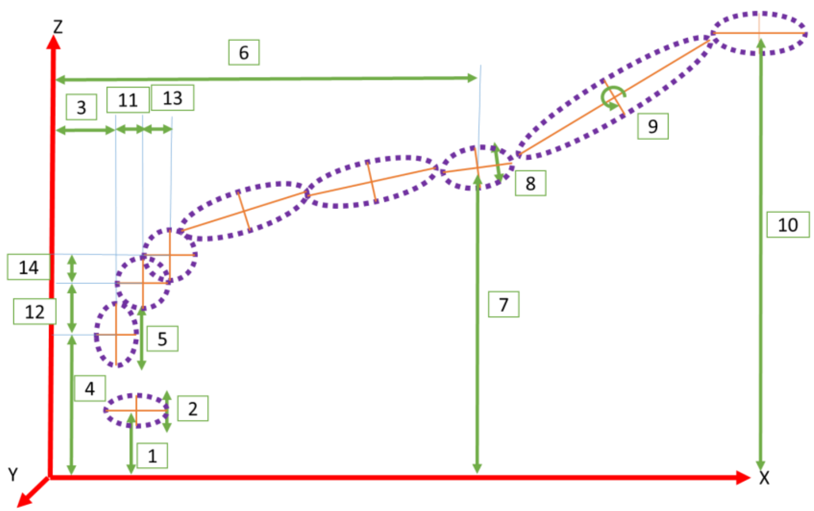
Car outer Profile



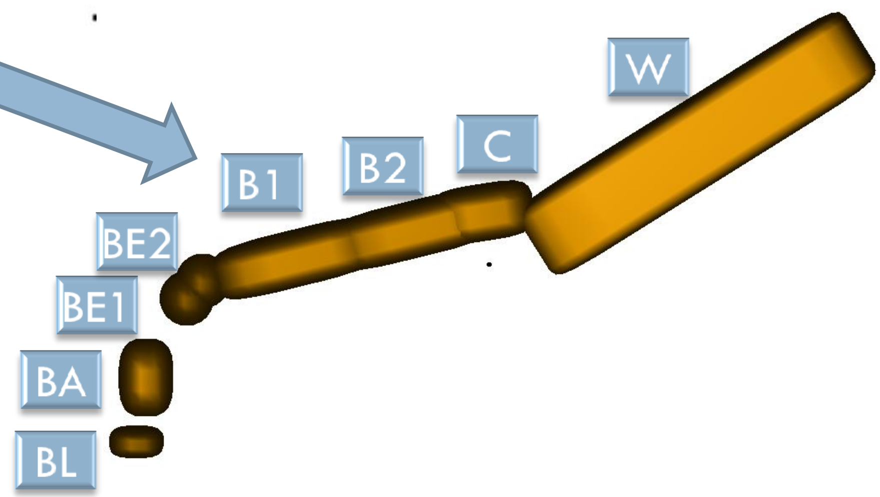
Vehicle profile

Steps to create a parameterized MADYMO model



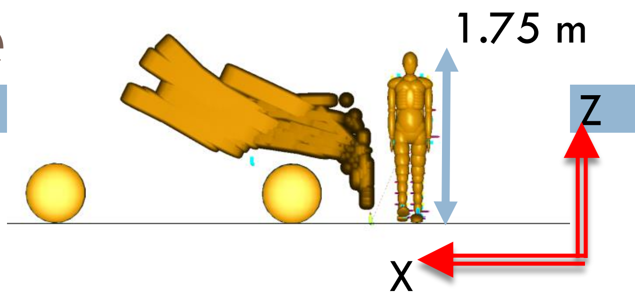


Convert measured parameters to values for approximate Multibody ellipsoid model of vehicle front



MADYMO parameterized model

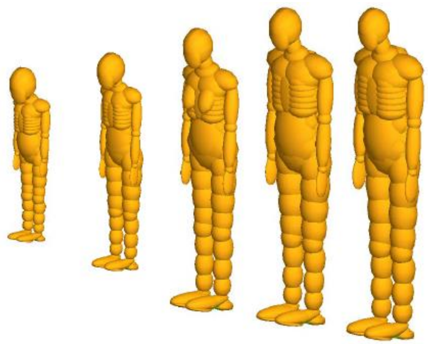
Range of values for Variables based on the design space



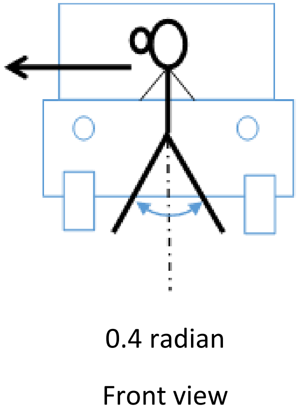
Parameter	Description	Min	Max
1	BL Ellipsoid CG location in Z direction	0.594	0.170
2	BL Ellipsoid width along Z direction	0.166	0.000
3	BA Ellipsoid CG location in X direction	-0.138	-0.010
4	BA Ellipsoid CG location in Z direction	0.895	0.411
5	BA Ellipsoid width along Z direction	0.320	0.038
6	C Ellipsoid CG location in X direction	-1.343	-0.471
7	C Ellipsoid CG location in Z direction	1.280	0.840
8	C Ellipsoid angle about Y axis	0.873	0.052
9	W Ellipsoid angle about Y axis	0.785	0.436
10	Location of point along Z direction on W ellipsoid along center plane indicated by red dot in Figure 4	1.976	1.370
11	BA Ellipsoid to BE1 Ellipsoid CG location distance in X direction	0.165	0.013
12	BA Ellipsoid to BE1 Ellipsoid CG location distance in Z direction	0.435	0.073
13	BE1 Ellipsoid to BE2 Ellipsoid CG location distance in X direction	0.219	0.000
14	BE1 Ellipsoid to BE2 Ellipsoid CG location distance in Z direction	0.222	0.03

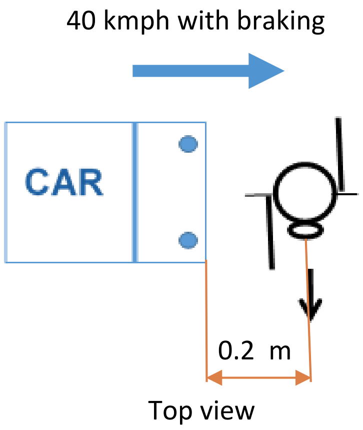
Simulation conditions

- Force deflection data from Martinez 2007
  - Orange level of F-D characteristics considered
  - The data collected from actual European vehicle fleet (subjected to Euro-NCAP tests)
- Geometrical limits
  - Sedan + SUV
  - Representative of Indian vehicle population
- Pedestrian Models
  - 3 y.o. and 6 y.o. child
  - 5th %le Female
  - 50th and 95th %le Male
- Braking values from Matsui 2011
  - Hard braking 4.7 m/s^2.
  - Time complete stop after initial hit = 100 ms



From TNO, Madymo human models, 2012





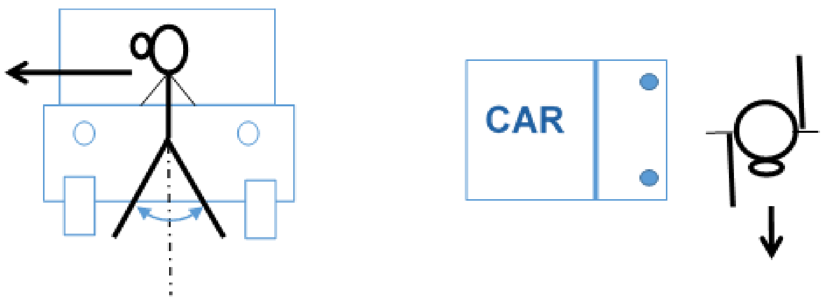
A single measure for threat – Injury Cost (IC)

- The AIS levels of injury severity mapped to an indicative "injury cost (IC)" using ISO: 13232
- "No way do such injury costs consider, nor are they intended to consider, the market level costs of a proposed protective device".
- The "costs" are a convenient, common basis for combining and comparing across body regions and crash tests and on a relative basis, different types, locations, and severities of injuries.
- The optimization problem being reduced to a single objective problem seems to converge to an optimal solution for the profile of a vehicle front-end design.

Body region	**AIS injury severity**	**Cost $**
Head	1	784
Head	2	3 807
Head	3	14 169
Head	4	72 349
Head	5	263 306
Neck	3	20 509
Neck	4	440 037
Neck	5	530 695

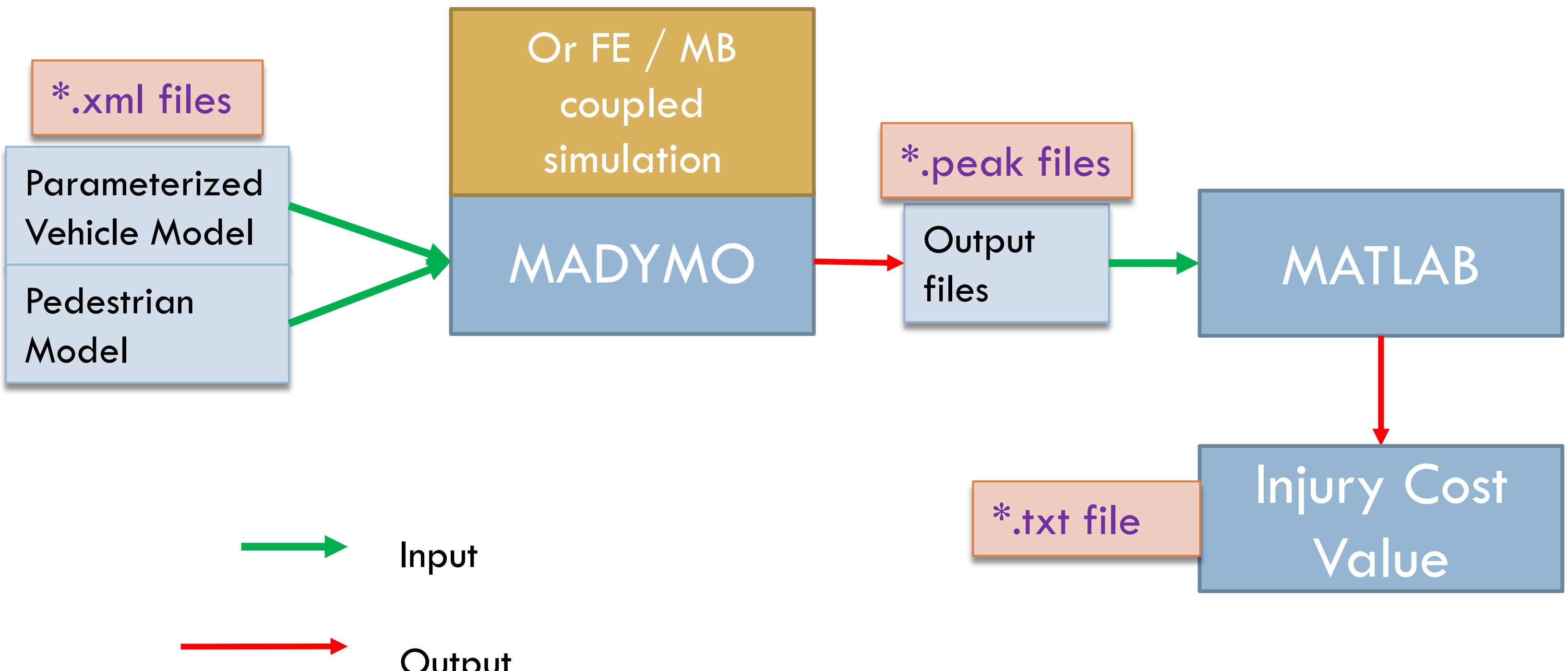
ISO 13232:part 5

How to compute IC from Simulation ?



$$WIC = f(HIC_i, Niji, a_{sternum_i}, VCi, FFCi, TIi)$$

for i=1,2..4(3C,6C,50M, 5F, 95M)



Calculation of IC

Body Region
- Head
- Neck
- Thorax
- Lower Extremity

Injury Measures
- HIC
- Nij
- VC
- Sternum Peak acceleration
- FFC
- TI

AIS
- Injury Risk Curves

Injury Cost
- Injury Cost = Medical Cost + Ancillary Costs

HIC to AIS		
HIC	AIS Code	Level Of Brain Concussion And Head Injury
135 – 519	1	Headache or dizziness
520 – 899	2	Unconscious less than 1 hour – linear fracture
900 – 1254	3	Unconscious 1 – 6 hours – depressed fracture
1255 – 1574	4	Unconscious 6 – 24 hours – open fracture
1575 – 1859	5	Unconscious greater than 25 hours – large haematoma
> 1860	6	Non survivable

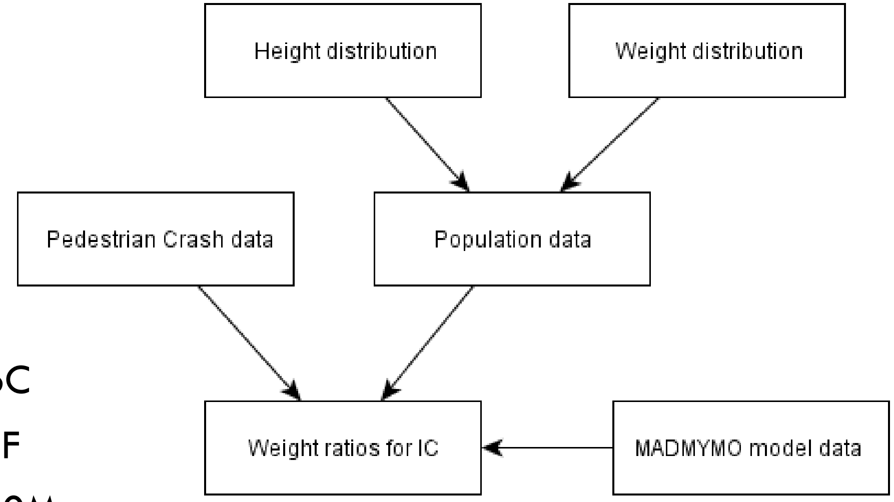
*Table taken from Payne and patel,2001

Injury Values obtained	Car 1_50		
	Value	AIS	Cost
HIC	793	2	14625
Nij	0.369	1	0
VC	0.002	0	0
FFC (kN)	10.9	4	128302
TI	0.31	0	
Force above knee on femur (kN)	11.17	4	
Lower Extremity PPI	0.27		
Total Injury Cost (USD)			142927

*Costs calculated based on ISO 13232:part 5

IC calculation for pedestrian population

Total potential IC for a population = x_1 * IC 6C + x_2 * IC 5F + x_3 * IC 50M + x_4 * IC95M



Where,

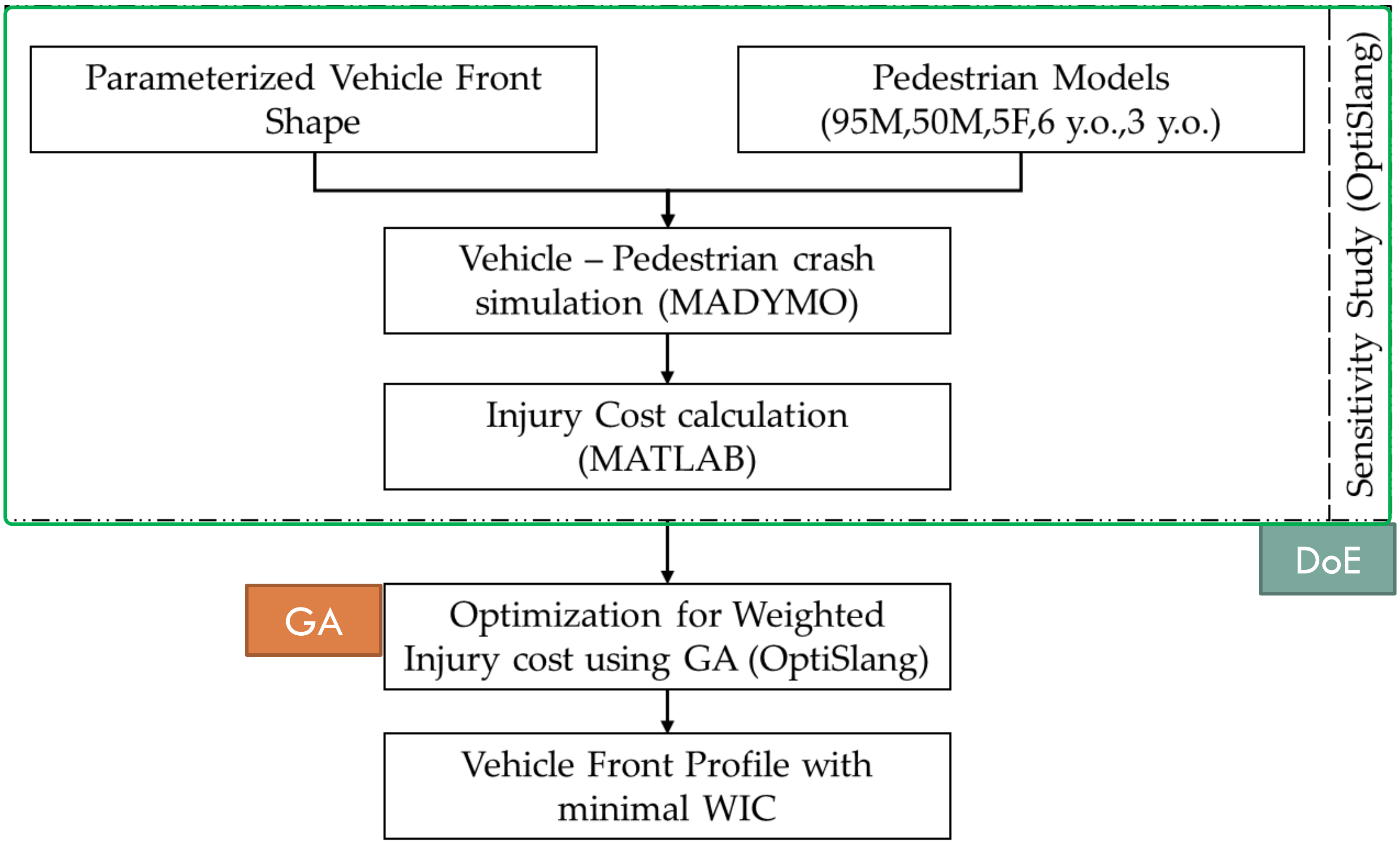
95 M	= 95th %le Male
50M	= 50th %le Male
5F	= 5^{th} %le Female
6C	= 6 year old Child
x_1	= weighting factor for IC calculated from 6C
x_2	= weighting factor for IC calculated from 5F
x_3	= weighting factor for IC calculated from 50M
x_4	= weighting factor for IC calculated from 95M

Equi-weight IC (EIC) = 0.25 * IC 6C + 0.25 * IC 5F + 0.25* IC 50M +0.25*IC95M

Population weighted IC (WIC)$^{+}$ = 0.45*IC of 6C + 0.47*IC of 50M +0.08*IC of 5F

$^{+}$ - Michigan, USA crash data and US Census data

Flow chart for Study - OptiSlang

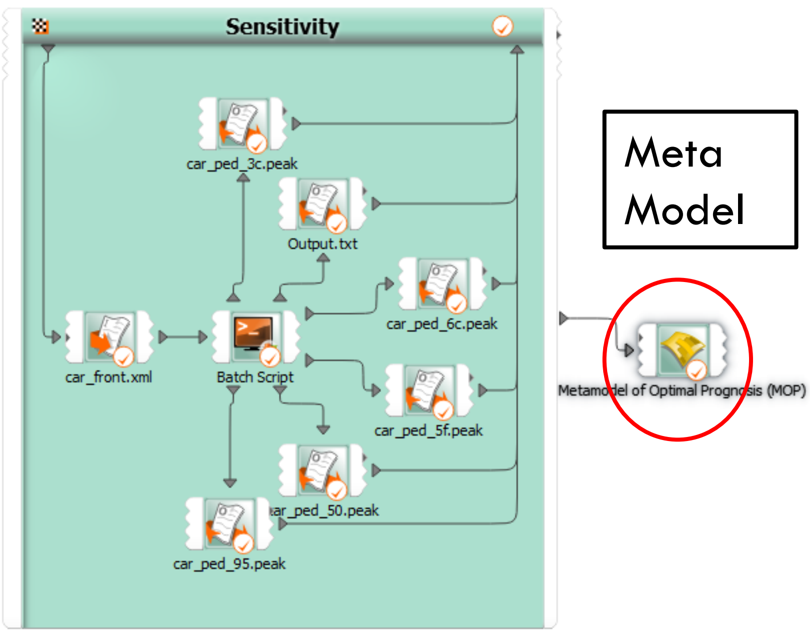


Results from OptiSlang

Design of Experiments followed by Optimization

Design of Experiments – Problem formulation

Sensitivity model



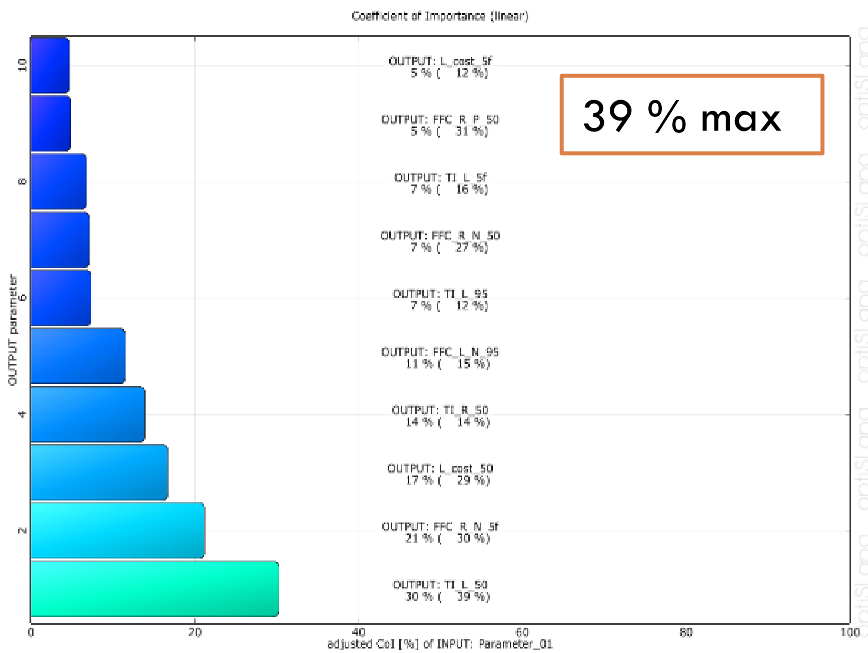
Input Variables

	Name	Parameter type	ference val	Constant	Value type	Resolution	Range		Range plot
1	Parameter_01	Deterministic	0.336		REAL	Continuous	0.17	0.594	
2	Parameter_02	Deterministic	0.073		REAL	Continuous	0.01	0.166	
3	Parameter_03	Deterministic	0.116		REAL	Continuous	0.01	0.138	
4	Parameter_04	Deterministic	0.74		REAL	Continuous	0.411	0.895	
5	Parameter_05	Deterministic	0.102		REAL	Continuous	0.038	0.32	
6	Parameter_06	Deterministic	1.326		REAL	Continuous	0.471	1.343	
7	Parameter_07	Deterministic	1.22		REAL	Continuous	0.84	1.28	
8	Parameter_08	Deterministic	0.307		REAL	Continuous	0.052	0.873	
9	Parameter_09	Deterministic	0.696		REAL	Continuous	0.436	0.785	
10	Parameter_10	Deterministic	1.683		REAL	Continuous	1.37	1.976	
11	Parameter_11	Deterministic	0.032		REAL	Continuous	0.013	0.165	
12	Parameter_12	Deterministic	0.259		REAL	Continuous	0.073	0.435	
13	Parameter_13	Deterministic	0.009		REAL	Continuous	0.01	0.219	
14	Parameter_14	Deterministic	0.017		REAL	Continuous	0.03	0.222	

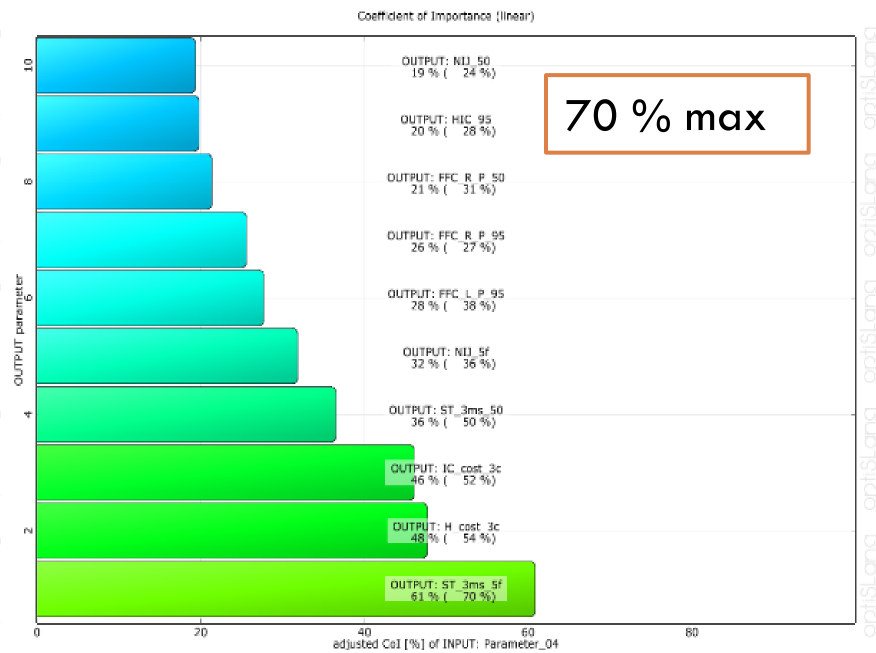
Continuous variables, range to avoid zero values : cover selected Indian vehicles dimensions

Coefficient of Importance - Linear

Parameter 01



Parameter 04



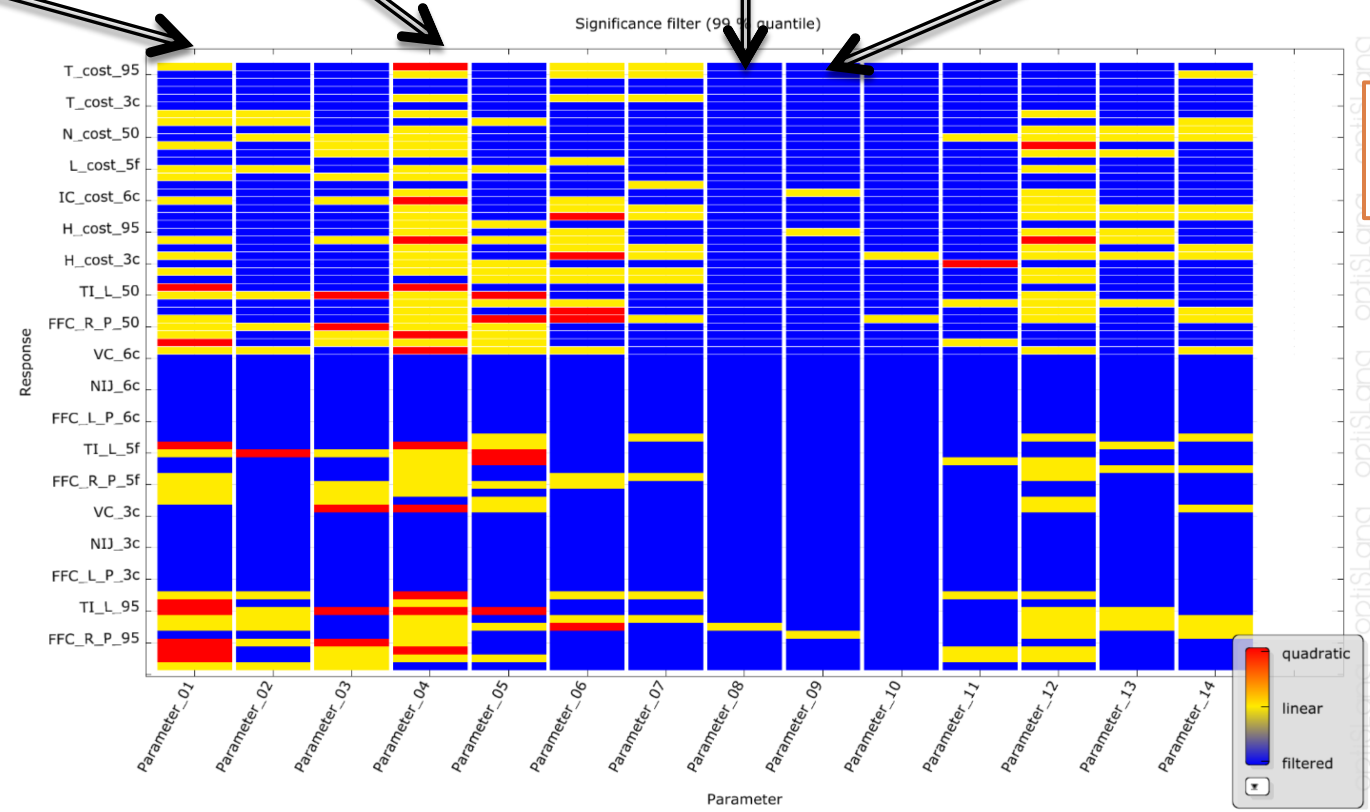
Higher the CoI (Linear) indicates better linear correlation with specified output parameter

Significance Filter

Bumper Lower - Z | Bumper Actual - Z | Cowl - θy | Windscreen - θy

Significant

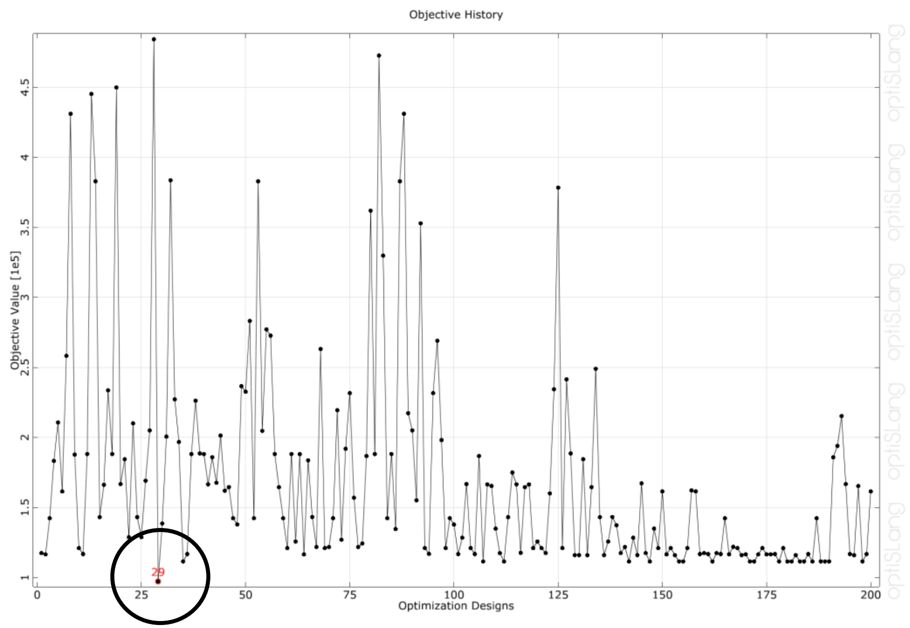
Non Significant



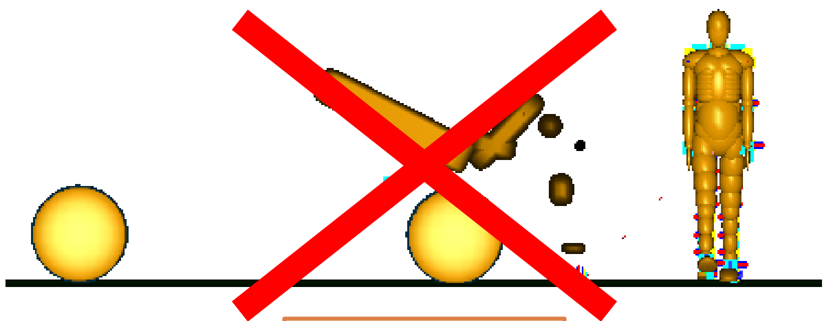
Parameters 01, 04 ,12, 05,06 indicate to have CoI with output.

Optimization results - Minimal Value

- GA process
- Minimization of WIC
- 100 samples per generation
- Stagnation in 2 generation

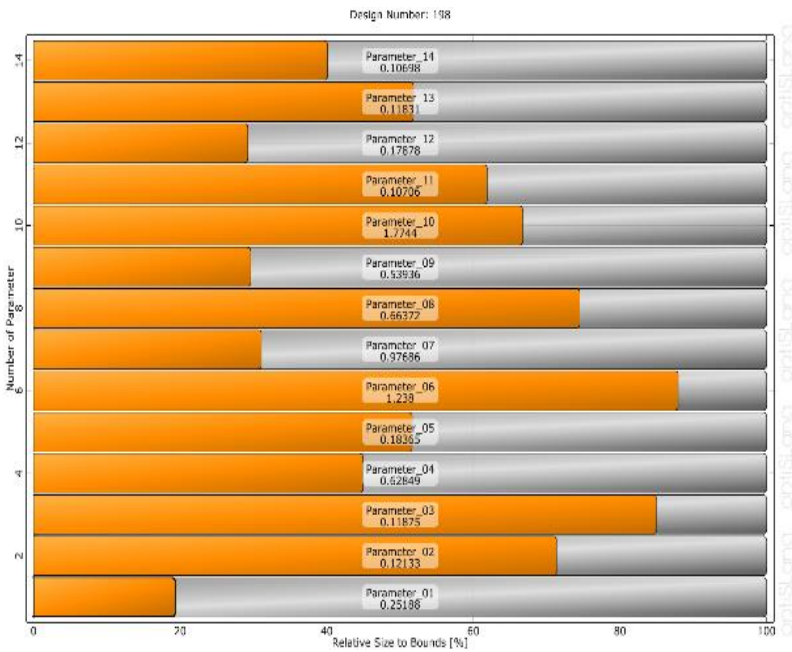


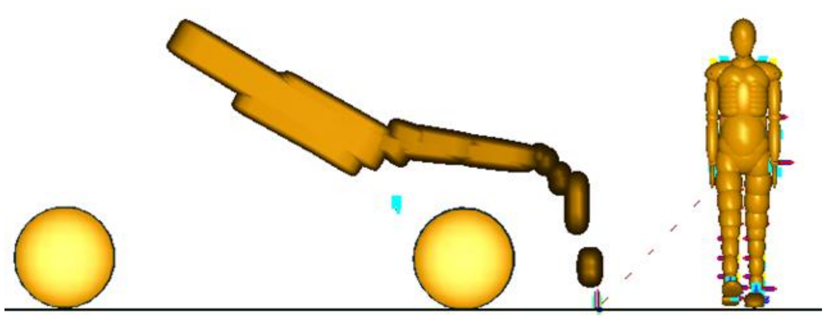
- Design 29 was found to be least WIC value.
- Design 29 not acceptable
  - Driver visibility
  - Non-conventional look



DESIGN 29

Optimal Designs





<u>Figure</u> :

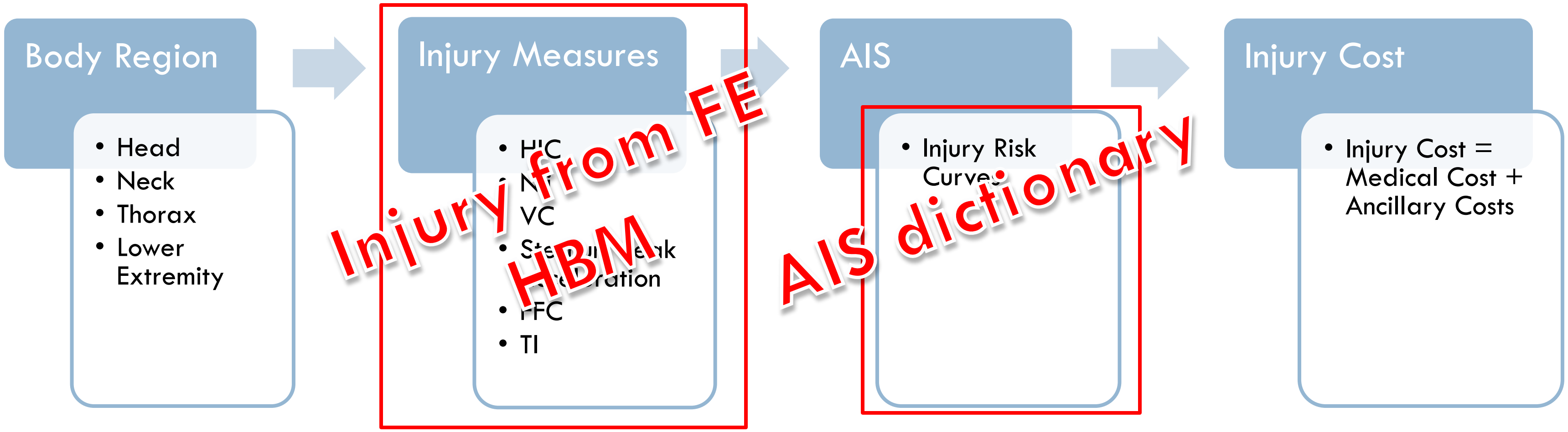
- Variable values of one of the designs
- Gray represents the total range

- 14 more designs had WIC values 111534 USD.
- The shape corresponds to similar values
  - Bumper to ground - 0.25 m
  - Bumper width -0.38 m
  - Bonnet leading edge height from ground - 0.85 m
  - Bonnet length - 1.12m

Conclusion

- The methodology allows a step by step identification and formulation of vehicle profile optimization problem
- The results indicate
  - Multiple solutions of non-significant variables as identified in DoE
  - Almost similar solutions from significant variables indicating <u>one solution</u> in the range considered.

Bigger Picture



- With better human models like Human Body FE model, and validated FE car models a better injury prediction can be performed.
- With more crash and population anthropometry data, a suitable WIC tuned for Indian conditions* can also be developed.
- A robust solution with OptiSlang
- An appropriate research methodology

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