Risk assessment in HyCoRA project – Need of data for the quantitative model

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Quantitative risk model

To consider the fuel quality risk in quantitative terms:

- ✓ transform the qualitative risk models into quantifiable format
- ✓ simplify the mathematical model, where applicable (or necessary), to facilitate its quantification
- ✓ capture the information required on model variables

- ❑ fuel quality risk is measured as the likelihood of experiencing adverse effects in the FCEV population and associated damage compensation costs
- ❑ model allows calculation of the *expected damage compensation cost per FCEV refuelling*
- ❑ probability data regarding model variables are needed as input

Bayesian Network (BN) model

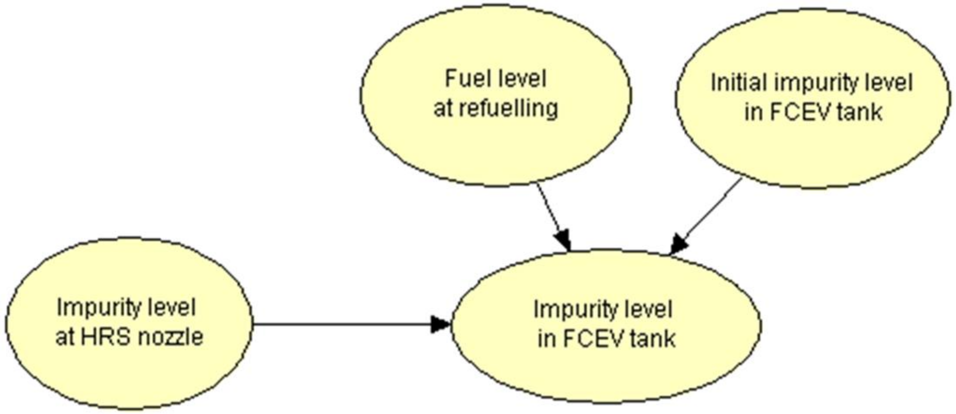
- directed acyclic graph model comprised of nodes and directed arcs
  - nodes represent random variables with an associated probability distribution for their possible values/states (continuous or discrete)
    - ’child node’: a dependent variable directly influenced by another variable
    - ’parent node’: influencing variable pointing directly to another variable
    - ’root node’: node with no ’parents’

Bayesian Network (BN) model

- directed arcs indicate the conditional probabilistic dependence between the connected variables. (direction of the arc indicating the direction of the dependence).
- loops leading back to a node are not allowed
- a conditional probability table is defined for each node to specify the probability of the variable being in a particular state considering each combination of the states of the parent node variables.
- With the BN model, the joint marginal distributions regarding the variables of interest can be calculated

Bayesian Network (BN) model - example

- an arbitrary impurity in fuel is considered
- intersted in the likelihood of experiencing certain impurity level in FCEV tank after a refuelling
- impurity level in FCEV tank after refuelling (ppm) depends on three variables with uncertainty
  - ✓ impurity level at HRS dispenser nozzle (ppm; ≤ 100 ppm equals 'clean')
  - ✓ FCEV tank fuel level at refuelling (% of tank volume)
  - ✓ impurity level in FCEV tank before refuelling (ppm)



Bayesian Network (BN) model - example

✓ Model specification: … data needs (i.e. variable states and state probabilities)

Fuel level at refuelling

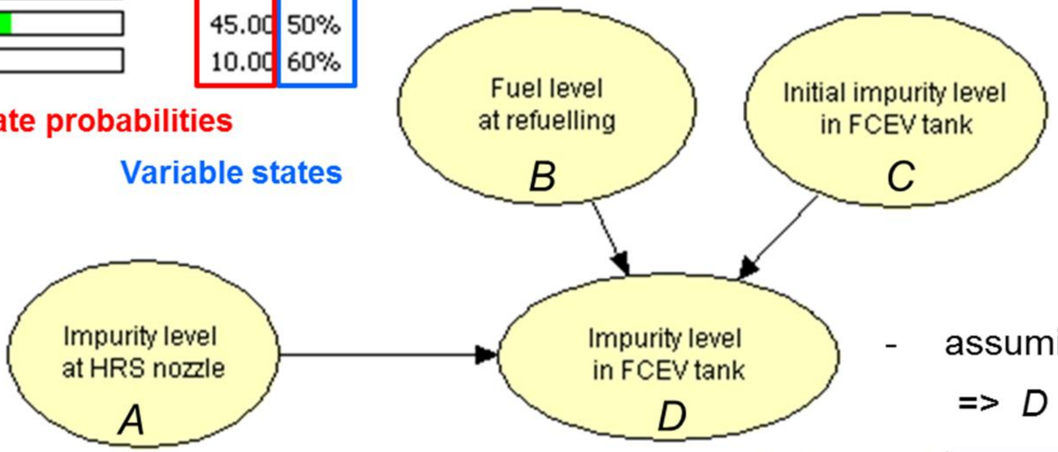
State probabilities	Variable states
5.00	10%
10.00	20%
10.00	30%
20.00	40%
45.00	50%
10.00	60%

State probabilities

Variable states

Initial impurity level in FCEV tank

100.00	<= 100 ppm
0.00	100-200 ppm
0.00	200-300 ppm
0.00	300-400 ppm



- assuming refilling to full tank volume:

=> $D = B \times C + (1-B) \times A$

Impurity level at HRS nozzle

95.90	<=100 ppm
3.00	100-200 ppm
1.00	200-300 ppm
0.10	300-400 ppm

Impurity level in FCEV tank | Initial impurity level in FCEV tank | Impurity level at HRS nozzle | Fuel level at r

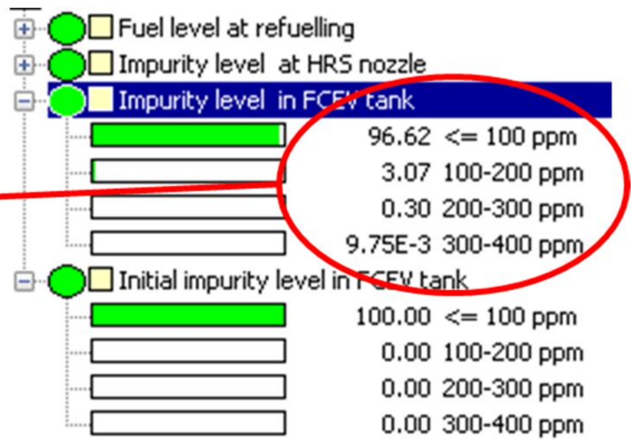
Initial impurity level in FCEV tank							
Fuel level at refuelling	10%				20%		
Impurity level at HRS nozzle	<=100…	100-20…	200-30…	300-40…	<=100…	100-20…	200-30…
<= 100 ppm	1	0.1	0	0	1	0.1	0
100-200 ppm	0	0.9	0.2	0	0	0.9	0.3
200-300 ppm	0	0	0.8	0.25	0	0	0.7
300-400 ppm	0	0	0	0.75	0	0	0

Conditional probability table for 'FCEV tank impurity level'

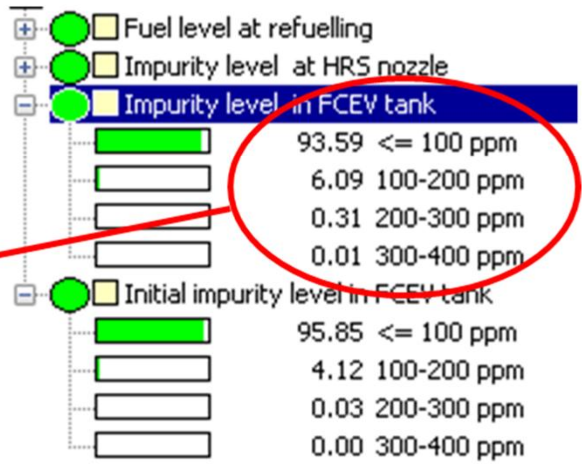
Bayesian Network (BN) model - example

✓ Model assessment /results:

- assuming all FCEVs are "clean" at refilling
  - 3.38% probability for a FCEV tank being contaminated (> 100 ppm) after a refill



- assuming certain proportion of FCEVs contaminated in refill surviving (without cleaning) to following refill
  - 70% if 100-200 ppm; 10% if 200-300 ppm; 0% if >300 ppm => **steady state** distribution for the initial impurity level in FCEVs
  - 6.41% probability for a FCEV tank being contaminated (> 100 ppm) after a refill



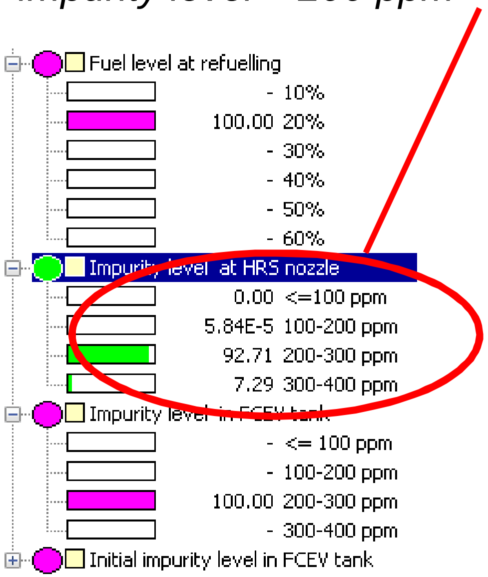
Bayesian Network (BN) model - example

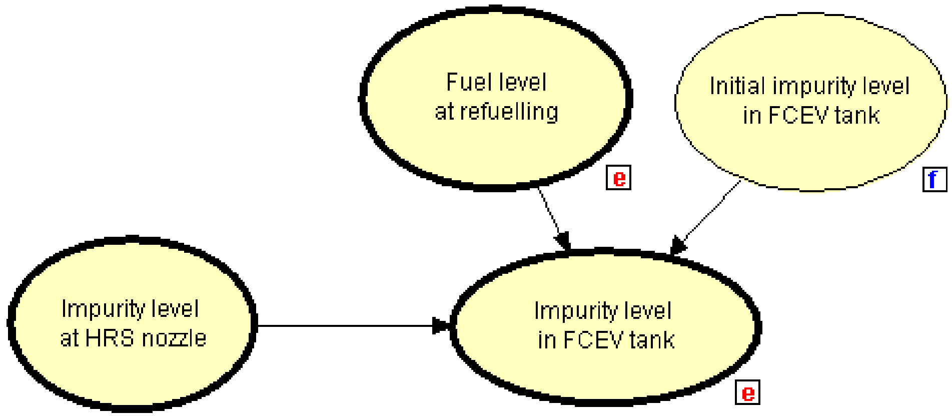
- BN model allows to capture complete set of scenarios regarding some variable, and the dependencies between those scenarios
- BN model also allows probabilistic backward inference given the information (i.e. evidence) on some of the model variables

  ✓ impurity level in FCEV tank found to be 240 ppm after refueling (and subsequently perceived problems)

  ✓ fuel level at refueling had been 20%; initial tank impurity level is not known (assumed steady-state)

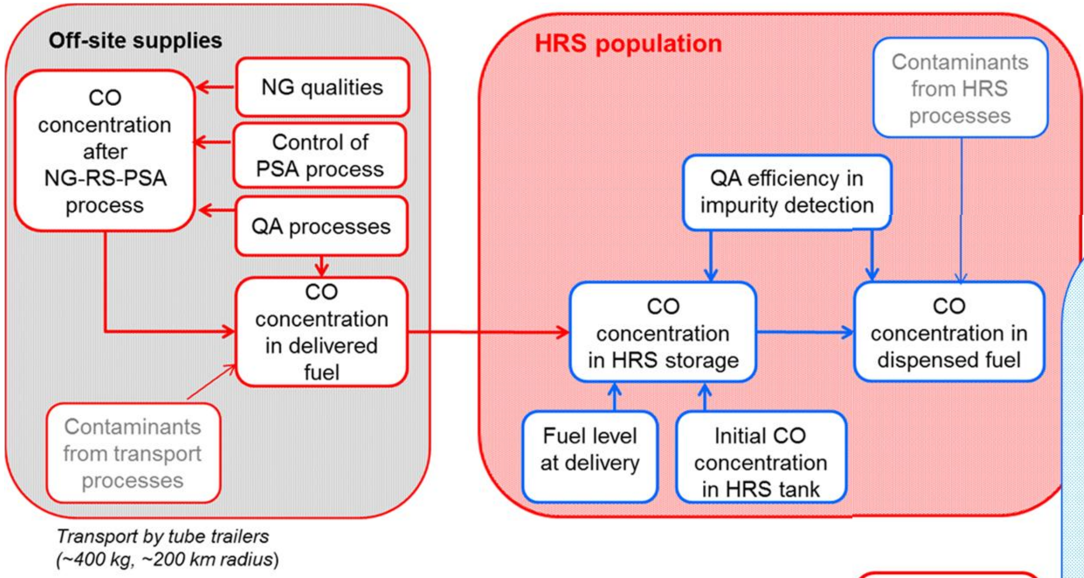
  => *it can be reasoned to be very likely that the fuel refuelled at the HRS has been severily contaminated; impurity level > 200 ppm*

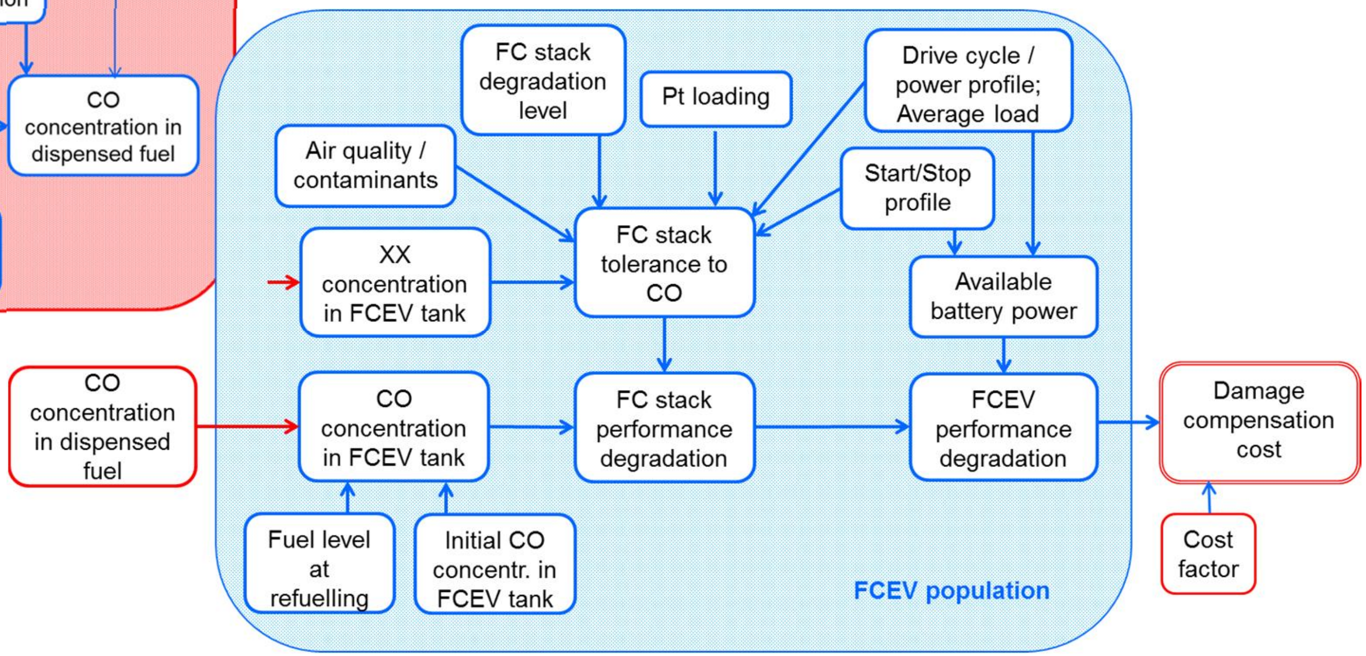




Data needs for the BN-based risk models

Data sources:
- ✓ Test campaigns, measurements
- ✓ Field data (industry)
- ✓ Literature
- ✓ Expert estimations





Variable X:
- ✓ *range of variation?*
- ✓ *relevant states/levels?*
- ✓ *state probabilities?*
- ✓ *p.d.f? (type, parameters)*

Data needs getting more accurately specified as the risk modeling progresses

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Data needs for the BN-based risk models: e.g.

Variable	Description	Levels/states	p.d.f.
CO in dispensed fuel	CO level at HRS dispenser nozzle (ppb)	<200 200-400 400-1000 >1000	Conditional prob. table. Determined by the HRS storage tank CO and QA efficiency at HRS in impurity detection
Refueling level	FCEV tank fuel level when entering refuelling (% of tank volume)	>20 20-40 40-50 50-60 >60	p.d.f. based on refueling records from HRSs (data published in the U.S.?)
Intial tank CO	CO level in FCEV tank before refuelling (ppb)	<200 200-400 400-1000 >1000	Steady state distrib. based on FCEVs' survivability on fuel impurities
Refueled tank CO	CO level in FCEV tank after refuelling (ppb) [1/] *Refilling to full tank capacity assumed.*	<200 200-400 400-1000 >1000	Conditional prob. table. Determined by the refueling level, initial tank CO and dispensed fuel CO[1/]

Data needs for the BN-based risk models: e.g.

Variable	Description	Levels/states	p.d.f.
FC stack tolerance to CO			
FC stack performance degradation	Drop in stack output voltage (mV)		
FCEV performance degradation	User perceived adverse effect in FCEV operation	✓ No / marginal ✓ Power reduction by X % ✓ Shutdown & H_2 purge ✓ Stack change	
Battery power	Battery power available in FCEV to compensate the reduced FC stack output		
Cost factor	Damage compensation cost from FCEV performance degradation	€ per degradation level	

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Data needs for the BN-based risk models: e.g.

Variable	Description	Levels/states	p.d.f.
Pt loading	Initial amount of anode Pt catalyst (mg/cm^2)	Currently 0.2-0.4 (pure Pt) Aim in automotive applications: 0.1, 0.05	
FC stack degradation level	Operating history caused FC stack degradation (% of ‘new’)		
Air quality			
Refueled tank XX	Impurity XX level in FCEV tank after refuelling (ppb)		
Start/Stop profile	FC stack start and stop intervals		
Drive cycle power profile	FC stack load variation		

Data needs for the BN-based risk models: e.g.

Variable	Description	Levels/states	p.d.f.
CO in delivered fuel	CO level of delivered fuel at trailer delivery interface (ppb)	<200 200-400 400-1000 >1000	
HRS refilling level	HRS storage tank fuel level at refilling (% of storage volume)		
Initial HRS tank CO	CO level in HRS storage tank before refilling (ppb)	<200 200-400 400-1000 >1000	
Refilled HRS tank CO	CO level in HRS storage tank after trailer delivery (ppb) [1/] *Refilling to full HRS storage capacity assumed.*	<200 200-400 400-1000 >1000	Conditional prob. table. Determined by HRS refilling level, initial HRS tank CO and delivered fuel CO[1/]
QA efficiency			

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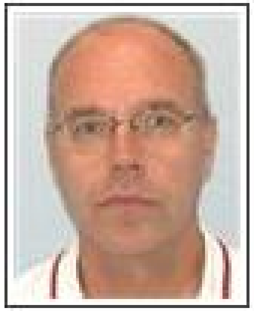
Thank you!

- Contact info:



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