Risk Modelling of a Hydrogen Refuelling Station using a Bayesian Network

3RD INTERNATIONAL CONFERENCE HYDROGEN SAFETY

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MANAGING RISK DNV

ELIMINATING RISK IS NOT AN OPTION

It’s how you manage your most critical risks

Motivation: Enhancing the basis for decision making

- Risk analysis is a powerful tool to be used as an integral part of the decision making
- Traditional approach to risk analysis in applying historic data cannot (directly) be applied to new disciplines involving emerging risks
- Requirements to the risk analysis:
  - The risk analysis must be transparent
  - Risk must be measured on scale that allows full integration into the decision process: E [€]
  - Transparent trade-off between different event categories
- Modelling: detailed knowledge about potential losses categories and how these may materialise
- Mitigation: knowledge of most likely causes leading to the losses
- Example: Risk modelling of a hydrogen refuelling station
  - Coarse risk analysis: risk as the expected monetary loss
  - Bayesian network bridges the gap between model formulation and analysis – enhances model realism

The case study: Hydrogen refuelling station

- Starting point: previous QRA of “virtual”, i.e. not a real HRS
- Gas dispensers
- Key input: 60 H2 gas (700 bar) and 25 LH2 refuelling operations per day
- Key input: 4 min to fill a car with 4 kg H2

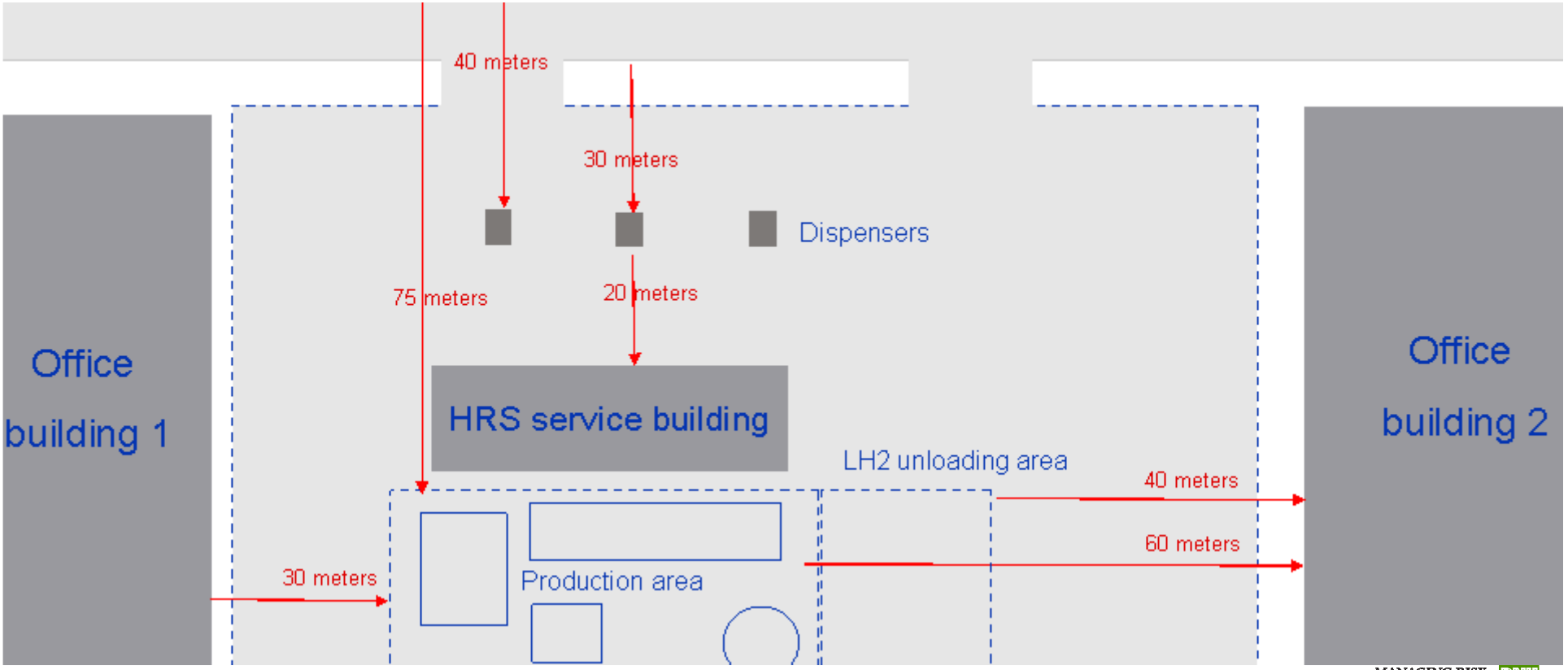


Illustration of the QRA process

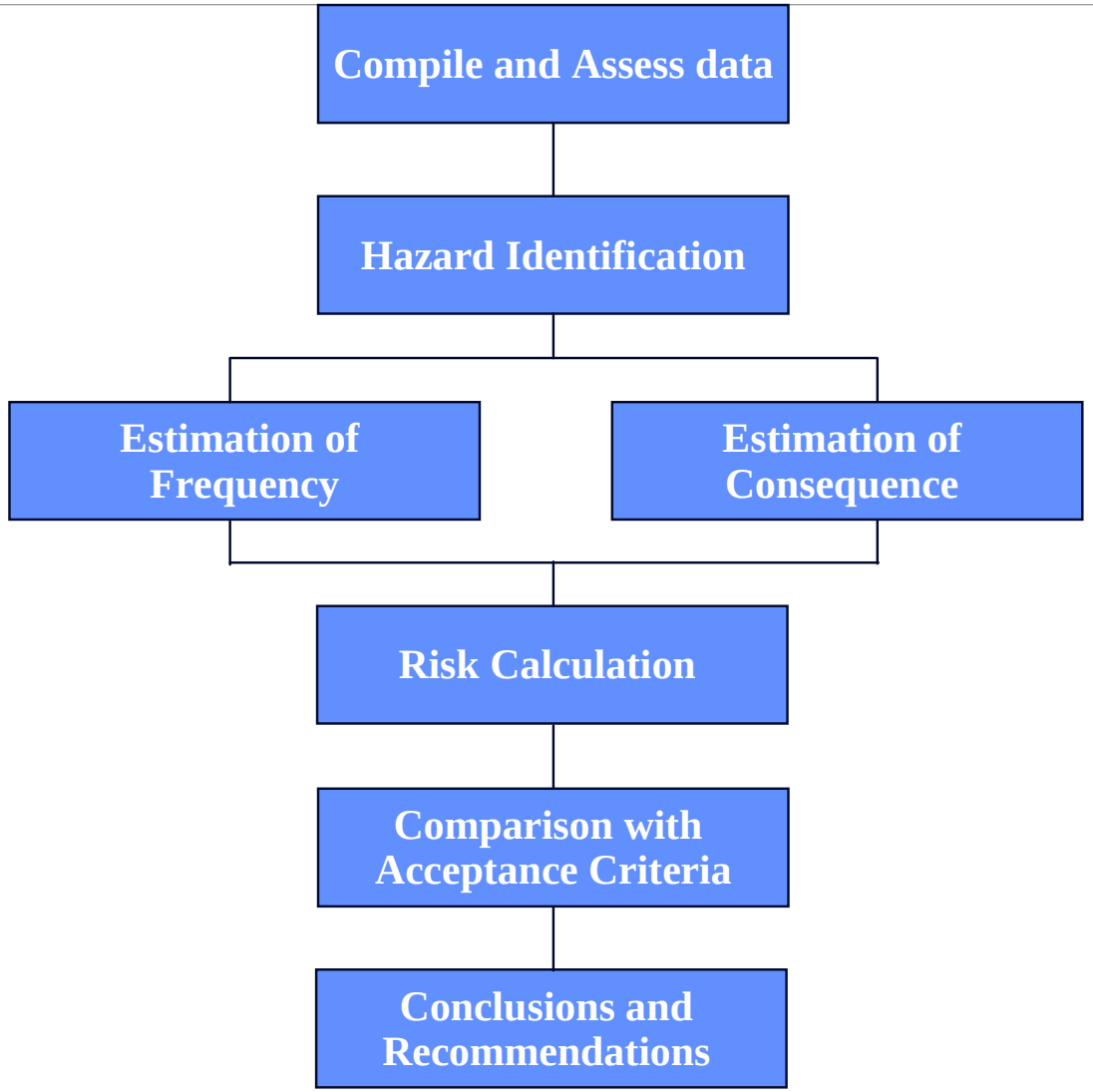
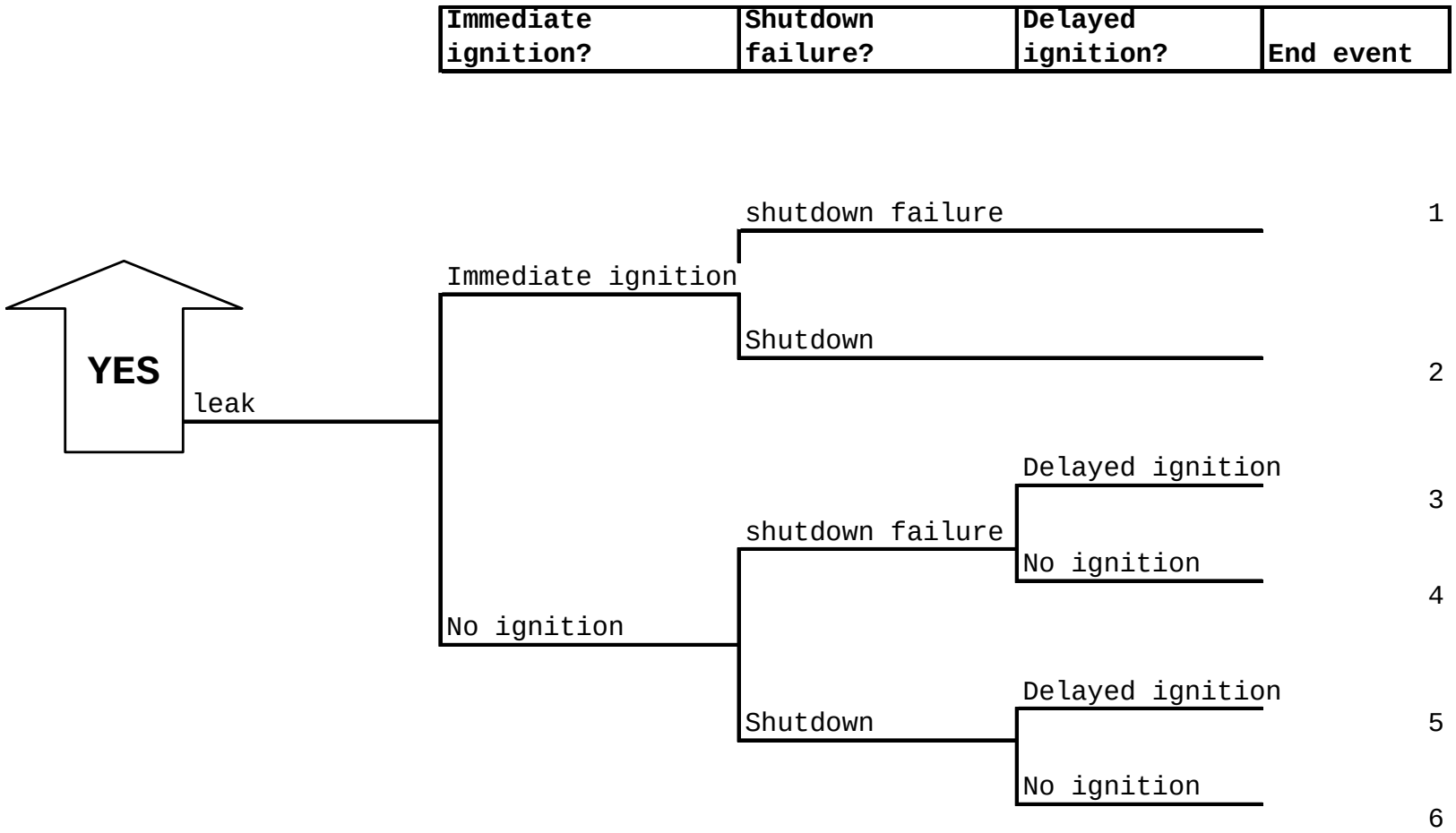


Illustration of the dispenser event tree - QRA



The consequence matrix

label		None	Negligible	Significant	Serious	Critical	Very Critical	Catastrophic
Consequence Class	**Abbreviation**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
First and second party	**PD**	Bruises and minor injuries that do not require hospital treatment	1 injury requiring hospital treatment	Several incidents requiring hospital treatment	Several incidents requiring hospital treatment. 1 disabled	1-10 killed	More than 10 killed	
Third party	**ND**	Uncomfortable, insecurity	Bruises and minor injuries that do not require hospital treatment	1 injury requiring hospital treatment	Several incidents requiring hospital treatment	Several incidents requiring hospital treatment. 1 disabled	1-10 killed	More than 10 killed
Production	**PR**		2 hour production stop	1 day production stop	1 week production stop	1 month production stop	1 year production stop	several years production stop
Material	**MK**		Minor repairs that can be done immediately by own crew	Repairs that take several days to carry out	Damage that takes weeks to repair and will affect the system	Damage that takes months to repair and cause serious consequences	Very large material damage	Significant parts of the system destroyed
Environment	**EM**		None/negligible	Minor environmental damage. Restored within days	Serious environmental damage. Restored within weeks	Serious environmental damage. Restored within months	Critical environmental damage. Takes 1-2 years to restore	Catastrophic environmental damage. Takes several years to restore
Monetary value (€)		**100**	**1 000**	**10 000**	**100 000**	**1 000 000**	**10 000 000**	**100 000 000**
Acceptability per year		**Negligible**	**Tolerable**	**Unwanted**	**Unacceptable**	**Unacceptable**	**Unacceptable**	**Unacceptable**

- All consequences in the same column are interchangeable
- Monetary scale allow for setting acceptability of annual expected monetary loss

Illustration of coarse risk analysis and aggregation

1	*CGH2_Disp*	*CGH2 Dispenser*				4,5	32 673
ID	**Incident**	**Cause**	**Frequency. One incident per**	**Barrier efficiency**	**Consequence**	**Risk class**	**Estimated Loss**
P1.17	Flash fire due to large leakage		(-2) 100-1000 year	0,1221	(ND7) 1-10 killed	4,1	12 210
P1.18	Flash fire due to large leakage		(-2) 100-1000 year	0,257409402	(PR4) 1 day production stop	1,4	26
P1.19	Flash fire due to large leakage		(-2) 100-1000 year	0,257409402	(MK5) Damage that takes weeks to repair and will affect the system	2,4	257
P1.20	Flash fire due to large leakage		(-2) 100-1000 year	0,257409402	(EM4) Minor environmental damage. Restored within days	1,4	26
P1.21	Flash and jet fire due to large leakage		(-2) 100-1000 year	0,152625	(ND7) 1-10 killed	4,2	15 263

Result of coarse risk analysis

Total monetary risk (Euro)

Hydrogen refilling station	Total Risk	Estimated loss
CGH2_Minor	3,2	1 534
CGH2_Major	4,5	31 139
Total	4,5	32 673

Distribution of losses among the different consequence categories

Customers

HyApproval	First and second party		Third party		Production		Material		Environment		Total Risk
	PD	Sum	ND	Sum	PR	Sum	MK	Sum	EM	Sum	
CGH2_Minor			219	219	626	626	626	626	63	63	1 534
CGH2_Major			30 047	30 047	399	399	631	631	63	63	31 139
Total			30 266	30 266	1 025	1 025	1 257	1 257	126	126	32 673

- Advantage: The cost-benefit analysis becomes straight forward
- Relation to risk becomes straight forward

Risk Matrix

Frequency (number per year)			Consequence						
			(2) None	(3) Negligible	(4) Significant	(5) Serious	(6) Critical	(7) Very Critical	(8) Catastrophic
			100 - 1 000	1 000 - 10 000	10 000 - 100 000	100 000 - 1 000 000	1 000 000 - 10 000 000	10 000 000 - 100 000 000	>100 000 000
	(2) Daily - monthly	>10 per year							
	(1) Monthly-yearly	1 - 10 per year							
	(0) 1-10 year	0.1 - 1 per year							
	(-1) 10-100 year	0.01 - 0.1 per year			CGH2_Minor				
	(-2) 100-1000 year	0.001 - 0.01 per year		P1.4; P1.8; P1.12	P1.2; P1.3; P1.6; P1.7; P1.9; P1.10; P1.11				
	(-3) 1000-10 000 year	0.0001 - 0.001 per year		P2.4	P1.1; P1.5; P2.2; P2.3; P2.6; P2.8; P2.12	P2.7; P2.10; P2.11	P2.1	HyApproval; CGH2_Major; P2.5; P2.9	
	(-4) 10 000-100 000 year	0.00001 - 0.0001 per year							
	(-5) > 100 000 year	<0.00001 per year							

Reveals:
Large losses caused by rare events

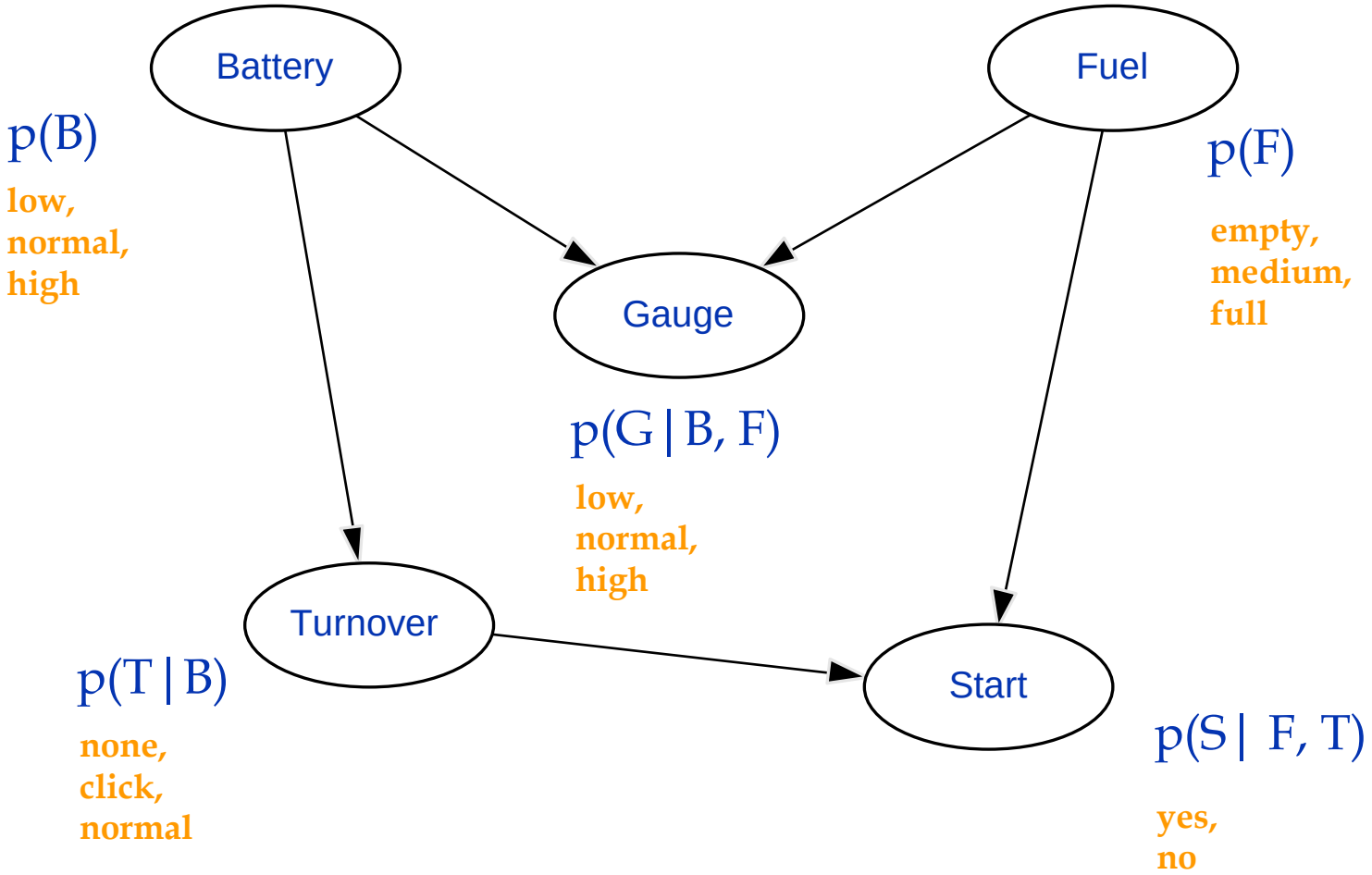
Modelling using Bayesian network

- A Bayesian network (BN)
  - is a graphical representation of uncertain quantities
  - reveals explicitly the probabilistic dependence between the set variables
  - is designed as a knowledge representation of the considered problem.

- A BN is a network with directed arcs and no cycles
- The nodes represents random variables and/or decisions
- Arcs into random variables indicate probabilistic dependence
- **Causal modelling most effectively does the model building**

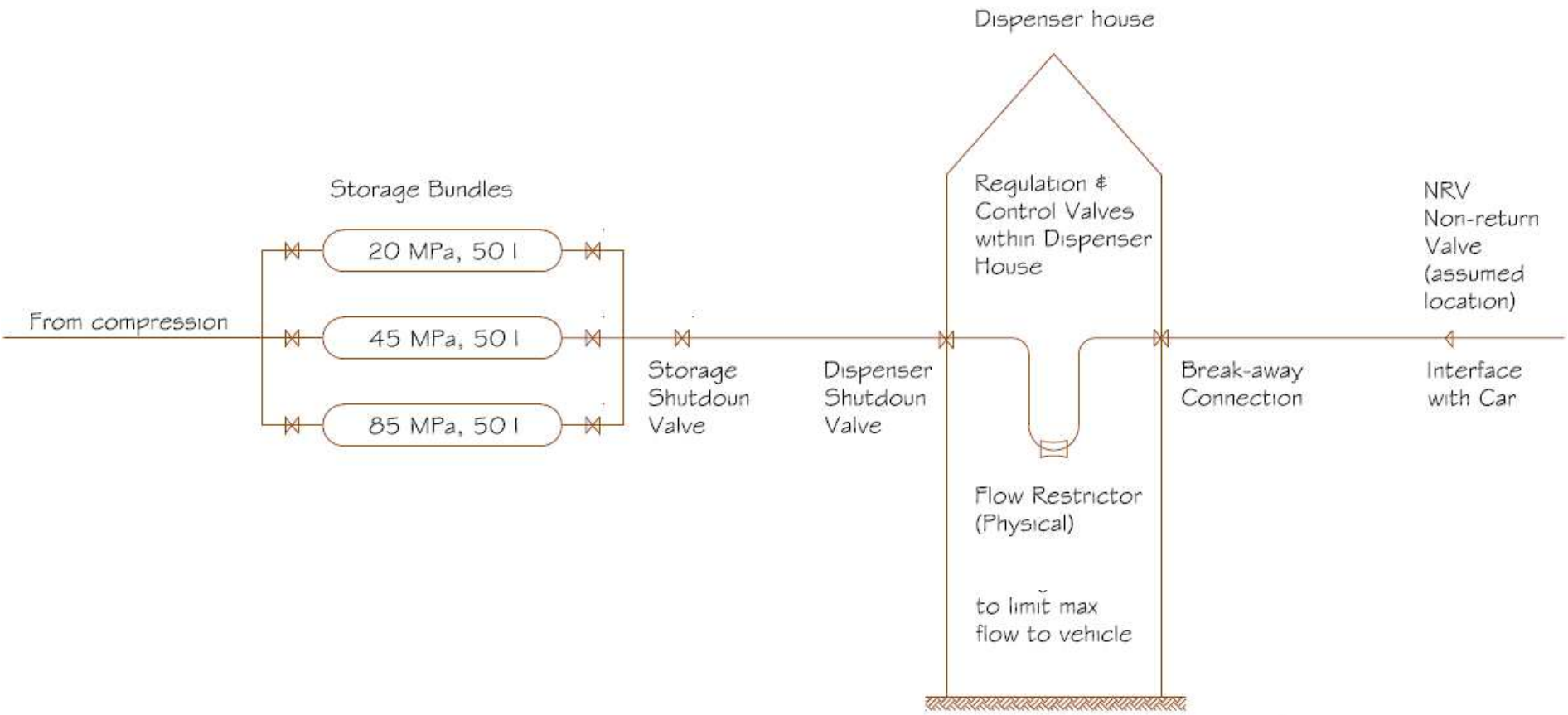
- Allows to identify the most likely scenario leading to specific unwanted events

BN for a set of variables: Will your car start?

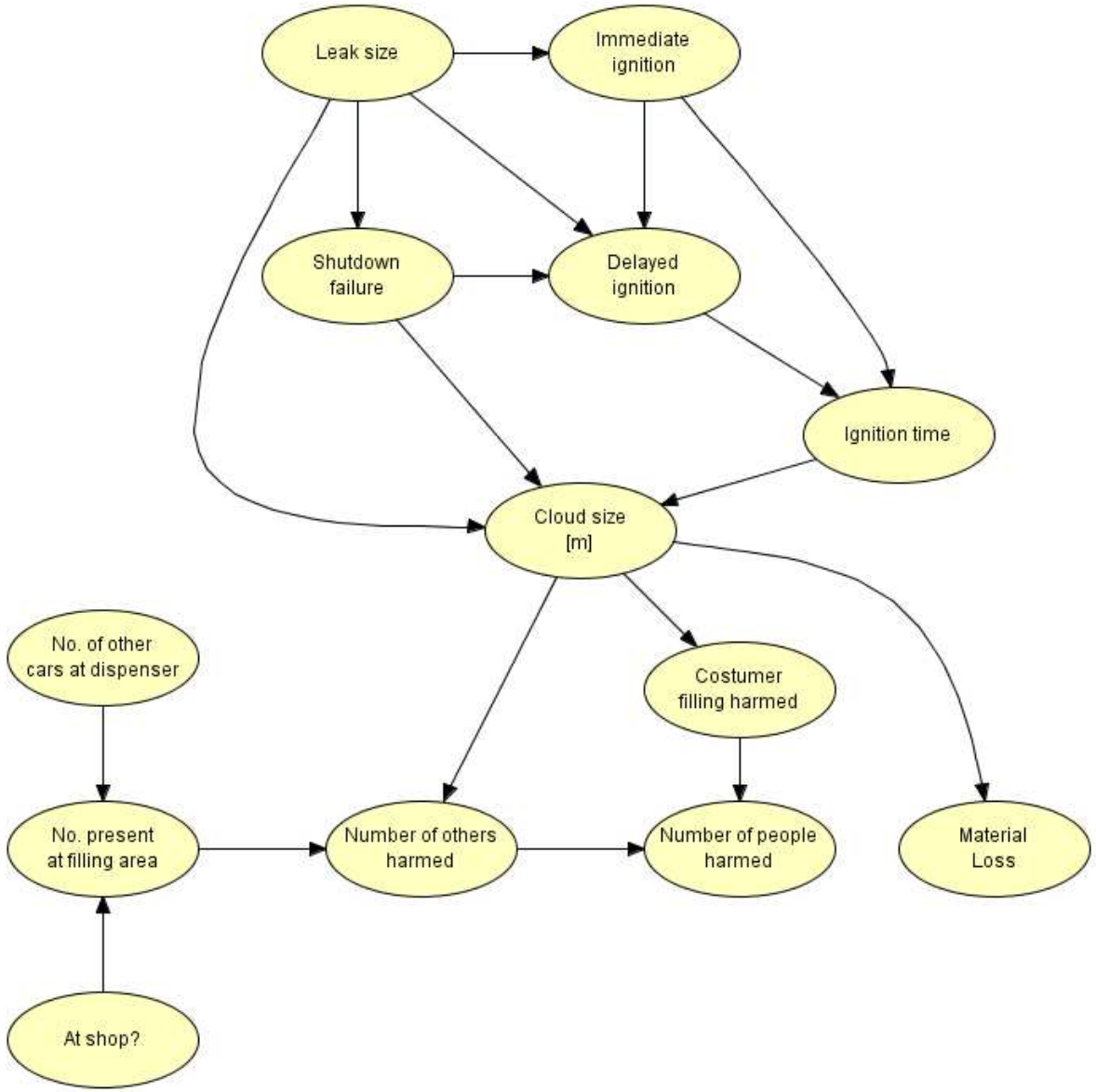


Directed Acyclic Graph

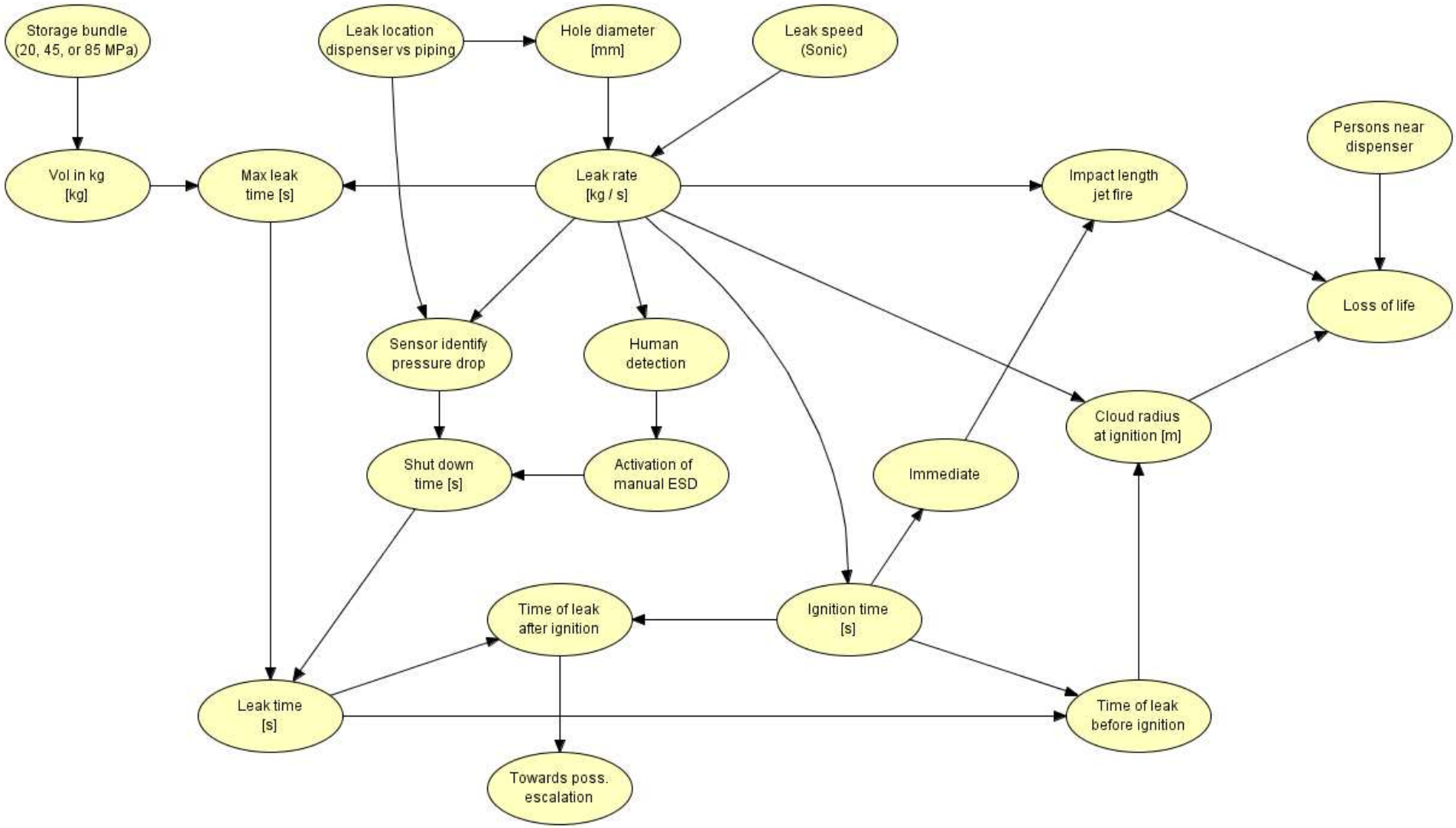
System outline



Bayesian network modelling of the dispenser area



Extended Bayesian network modelling of the dispenser area



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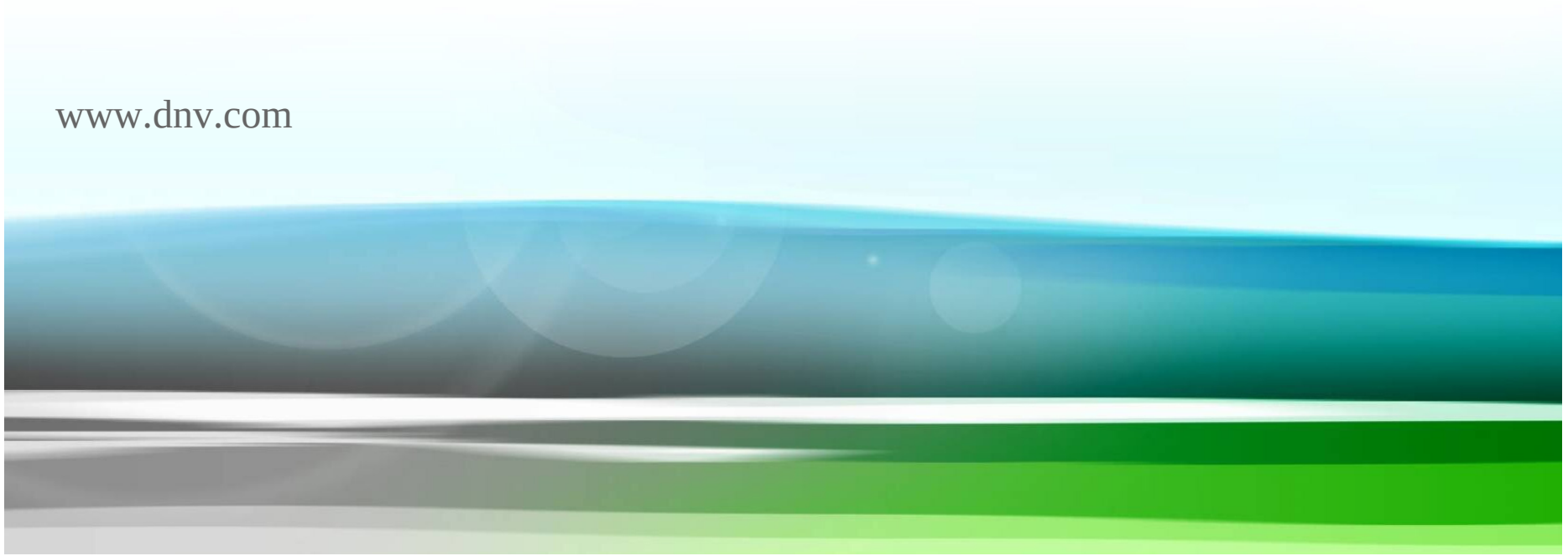

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