Systematic risk modeling in plastic and rubber recycling processes:

a future tool for process control, occupational safety, environmental risk management and consumer safety

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Introduction – Why should we recycle?

- The social demands of the environmental safety and the needs of recycling business operations are increasing as a result of diminishing natural resources.
- This means reusing and recycling existing materials and products in a sustainable way.
- Waste can be turned into a valuable resource
  - the Member States of the European Union produce 3 billion tonnes of waste every year!
- Recycling and resource-efficiency are effective ways to reduce climate change!

Introduction - Competitive zero-waste circular economy!

The European Commission proposed *the Circular Economy package 2014*. This package includes

- a 70% recycling target for municipal waste by 2030,
- an 80% recycling target for packaging materials by 2030 and
- a ban on landfilling of all recyclable and biodegradable waste by 2025.

"The European Commission is aiming to present a new, more ambitious Circular Economy package late in 2015, to transform Europe into a more competitive resource-efficient economy, addressing a range of economic sectors, including waste."

Source: http://ec.europa.eu/environment/circular-economy/index_en.htm

Background of the study:
Risks and issues to consider in Circular Economy

- Are there occupational and environmental health risks hidden into “the flow of circular economy”?
- Recycled waste materials may contain hazardous additives and biological or chemical contaminants which may affect the safe use of these materials.
- This can cause a variety of negative human health effects if hazardous substances enter into the recycling processes and accumulate in the products.
- Waste and recycling workers may also be exposed to hazardous substances when sorting and processing unsafe plastic waste materials.
- Unsafe recycled products containing harmful additives and contaminants may cause consumer exposure.

Background of the study: Risks and issues in plastic and rubber recycling

- A wide variety of plastics and rubbers are commercially available and their sorting is difficult in recycling processes
- Contaminants in plastic and rubber wastes
- The content of the post-consumer wastes
- Degradation products of polymers, additives and contaminants
- Microbial growth and activity
- Uncontrolled conditions in plastic and rubber recycling in third countries
- New materials, additives and processing methods = unknown threats?
- Most of the commercial products are not designed to be recyclable
- New materials are entering to the recycling processes (e.g. nanomaterials and composites)

Numerous additives in plastics and rubbers – possible risks in recycling?

- phthalate plasticizers
- flame retardants
- antioxidants
- heat and light stabilizers
- other plasticizers
- fragrances
- impact resistance
- enhancers
- pigments
- colorants
- dyestuffs
- flame retardants
- mould release agents
- foaming agents
- fillers
- antiblocker agents
- anti-fogging agents
- anti-static agents
- organic peroxides
- bio-stabilizers
- chemical blowing agents
- cross-linking agents
- high polymeric impact strength additives
- processing aids
- lubricants
- metal deactivators
- optical brighteners
- property modifiers
- reinforcements
- smoke and afterglow suppressants
- wetting agents
- etc.

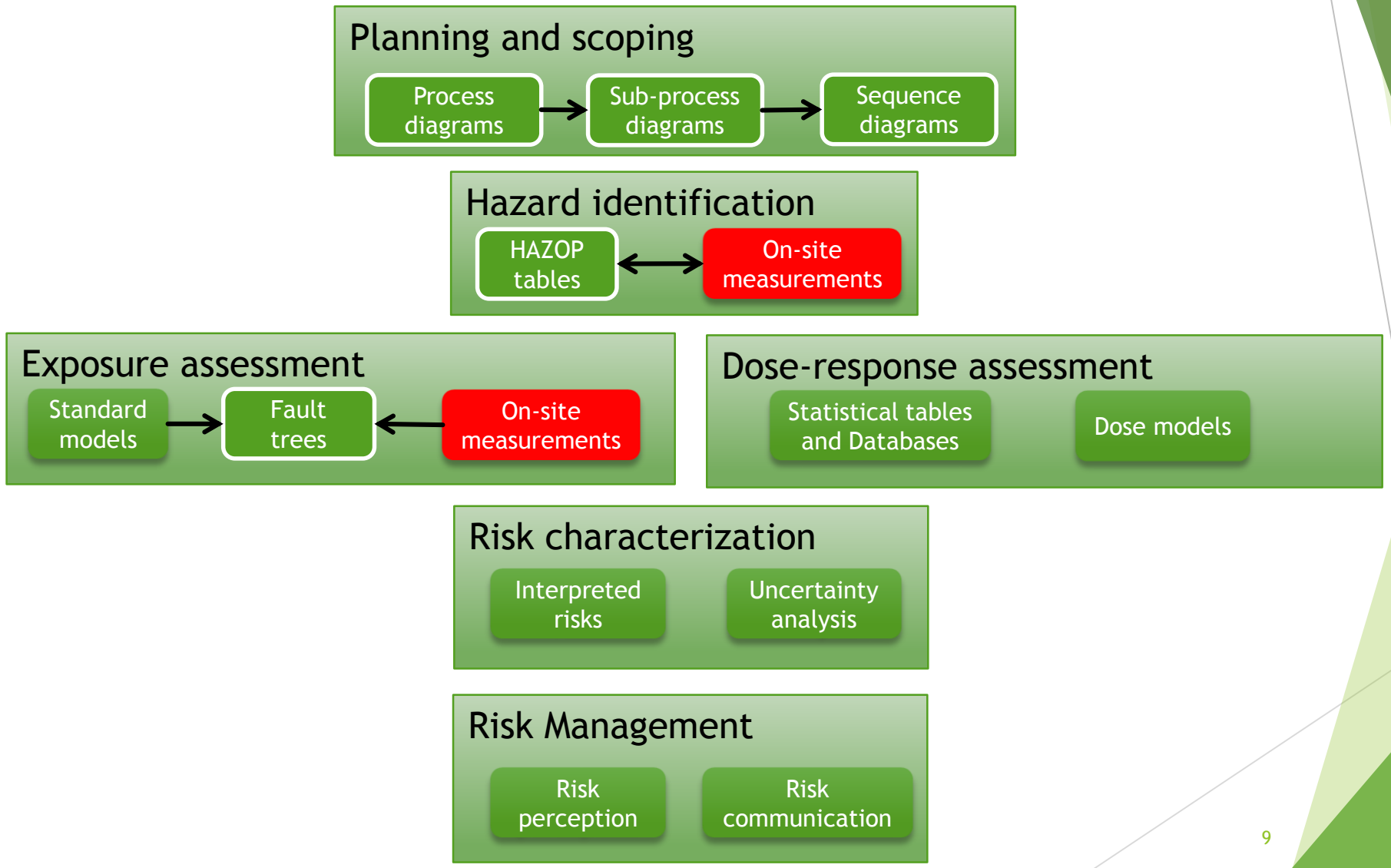
The aim of the study:
Systematic risk modeling method in plastic and rubber recycling processes

- There is an international need for systematic health, safety and environmental risk modeling and assessment in plastic and rubber recycling processes.
- Collaboration with industrial partners has revealed that applicable risk assessment tools are inadequate for plastic and rubber recycling processes.
- In our ongoing research we have discovered that systematic risk modeling has to cover all phases in recycling processes from waste sorting to product manufacturing.

Phases and Diagrams I

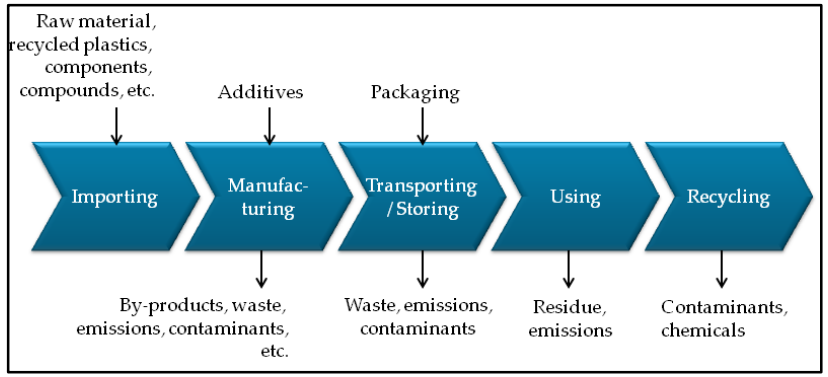
1. **Planning and Scoping:** Process (and sub-process) diagrams, Sequence diagrams
2. **Hazard Identification:** HAZOP tables, On-site measurements
3. **Dose-Response Assessment:** Statistical tables
4. **Exposure Assessment:** (characterization, identification, quantification): Standard models, On-site measurements, Fault trees
5. **Risk Characterization:** Interpreted path risk or cumulative risk, Uncertainty analysis
6. **Risk Management:** Risk perception and communication

Phases and Diagrams II

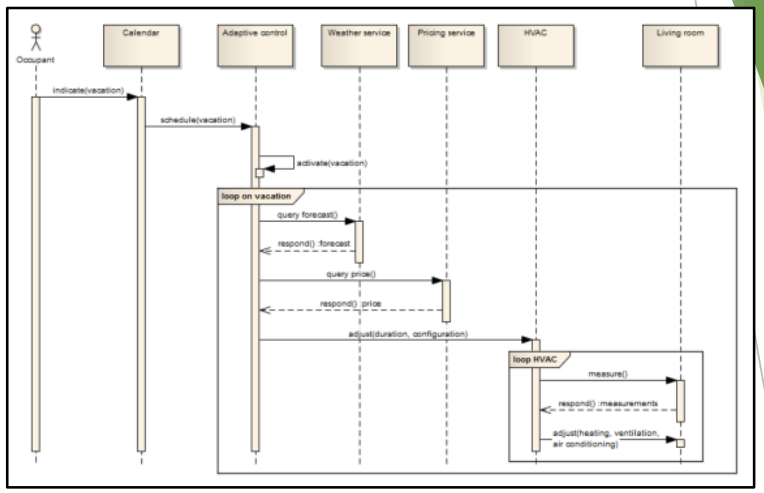


What Diagrams Look Like

Simplified process diagram:



Sequence diagram:



Fault tree (Fault tree handbook, NUREG-0492):

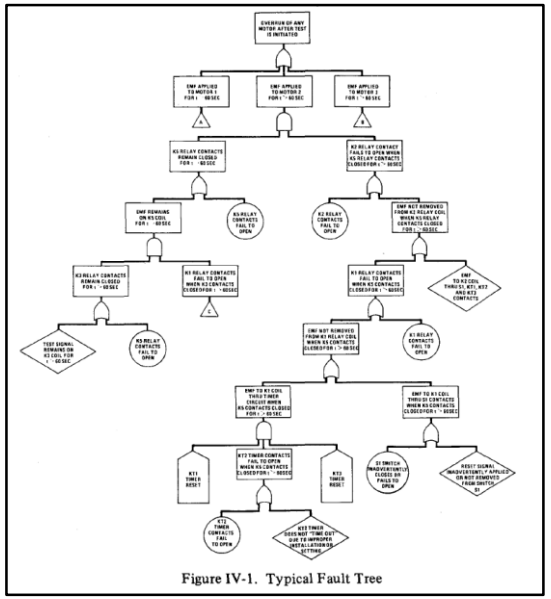


Figure IV-1. Typical Fault Tree

Hazard and operability study (HAZOP) table:

Component	calendar			**HAZOP**	OnVacation
Activity	schedule			**Author**	Mauno Rönkkö
Intention	schedules vacation period			**Date**	August 28, 2013
Deviation	**Cause**	**Consequence**	**Indicator**	**Safeguard**	**Correction**
missing	entry missing	not entering vacation mode	motion detectors, use of appliances	none	add calendar entry
	calendar is faulty	"	"	"	repair
faulty	"	"	"	"	
too late	incorrect entry	"	"	"	extend calendar
	calendar is faulty	"	"	"	repair
too short	incorrect entry	exits vacation mode too early	"	confirm duration when entering vacation mode	extend calendar entry
	calendar is faulty	"	"	"	repair
too early	incorrect entry	enters vacation mode too early	"	confirm mode switch	postpone calendar entry
	calendar is faulty	"	"	"	repair
too long	incorrect entry	stays in vacation mode for too long	"	confirm duration when entering vacation mode	shorten calendar entry
	calendar is faulty	"	"	"	repair

Occupational hygiene measurements (on-site measurements)

Occupational hygiene measurements included

- dusts
- metals
- microbes
- bioaerosols
- volatile organic compounds
- semi-volatile organic compounds

Measurements were performed on-site during

- sorting
- washing
- extrusion
- injection molding
- product manufacturing

Some results so far (on-site measurements)

- Occupational and environmental health risks are real issues in plastic and rubber recycling processes.
- Exposure to microbes and bioaerosols is high during the waste sorting and cleaning steps.
- Particle emissions are high during the extrusion and injection molding steps.
- Volatile and semivolatile organic compounds (VOCs and SVOCs) are emitted from melted plastic during the extrusion and injection moulding.
- Particle and gas emissions during the process are clearly depended on the quality and cleanliness of recycled plastics.
- Complexicity of gas emissions was confirmed during the on-site measurements.
- Employees have to be protected against bioaerosols and VOCs.
- Local exhaust ventilation together with proper design of production facilities are important to reduce the hazardous emissions.
- → work will continue with material emission analyses!

arvi
Material Value Chains

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