A stochastic programming approach for planning remanufacturing activities under uncertain returns and demand forecasts

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26 juin 2015

Plan

Plan

Context

Circular economy

"In a world with growing pressures on resources and the environment, the EU has no choice but to go for the transition to a resource-efficient and ultimately regenerative circular economy."

Manifesto for a Resource Efficient Europe, European Commission, 2012

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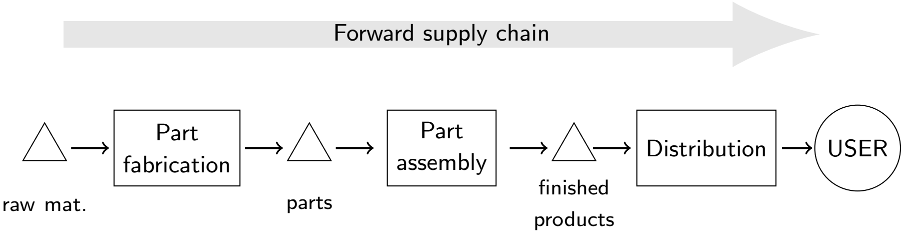
Reverse supply chains

- One possible way towards developing a circular economy
- Set of logistics and rehabilitation activities to transform end-of-life products returned by customers into once again usable products
- Main advantages:
  - Reduction in waste generation and environmental pollution
  - Decrease of natural resource consumption

Reverse logistics activities



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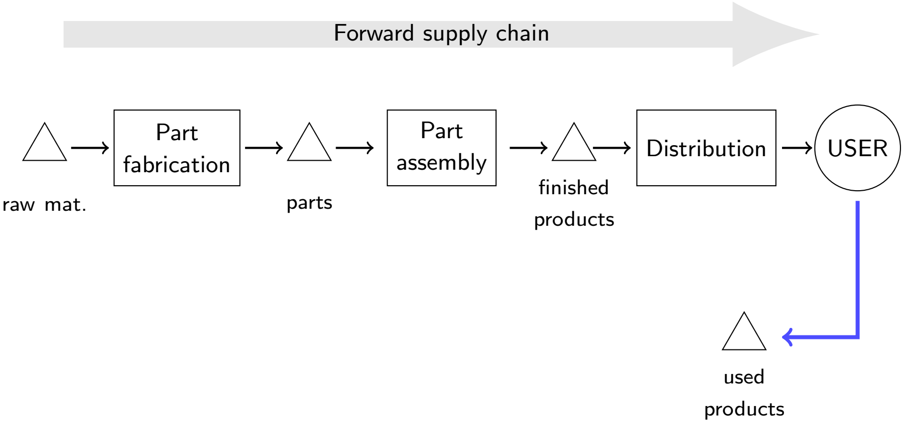

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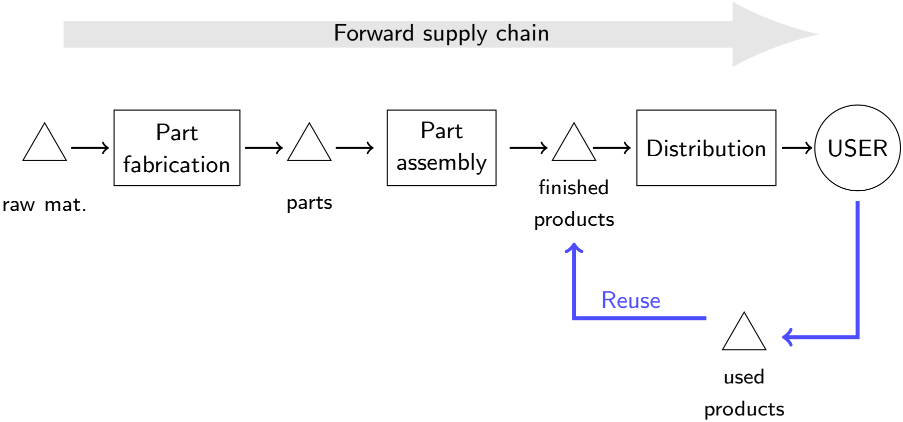

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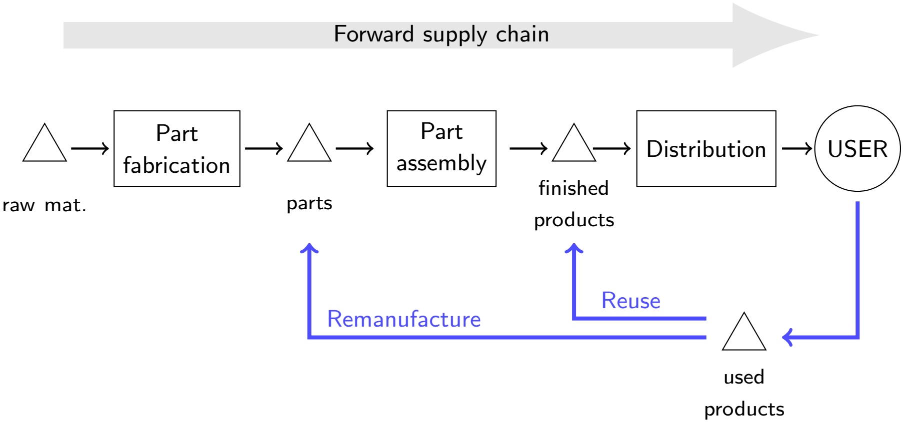

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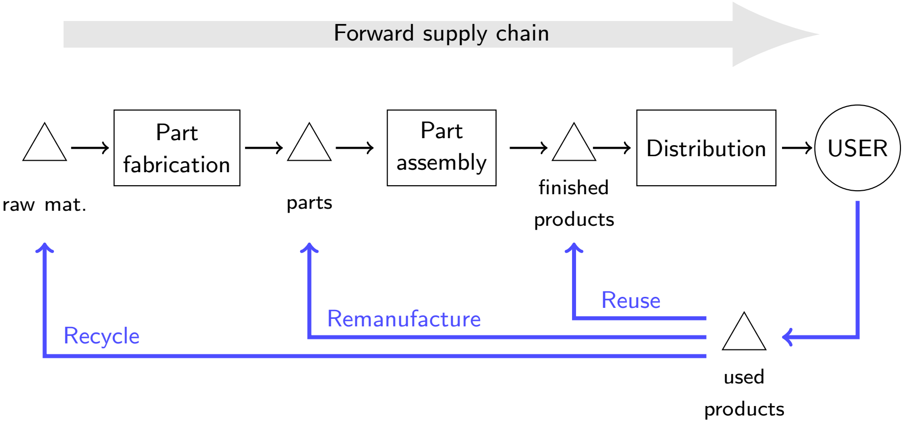

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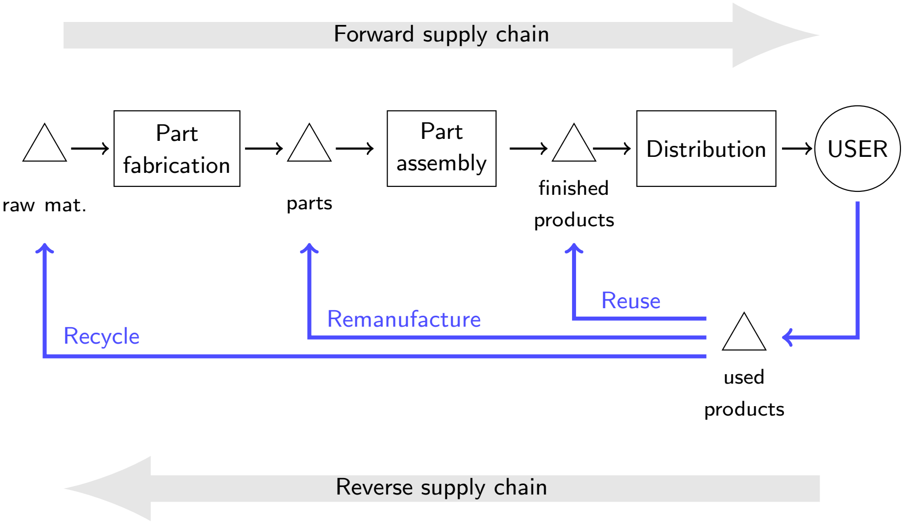

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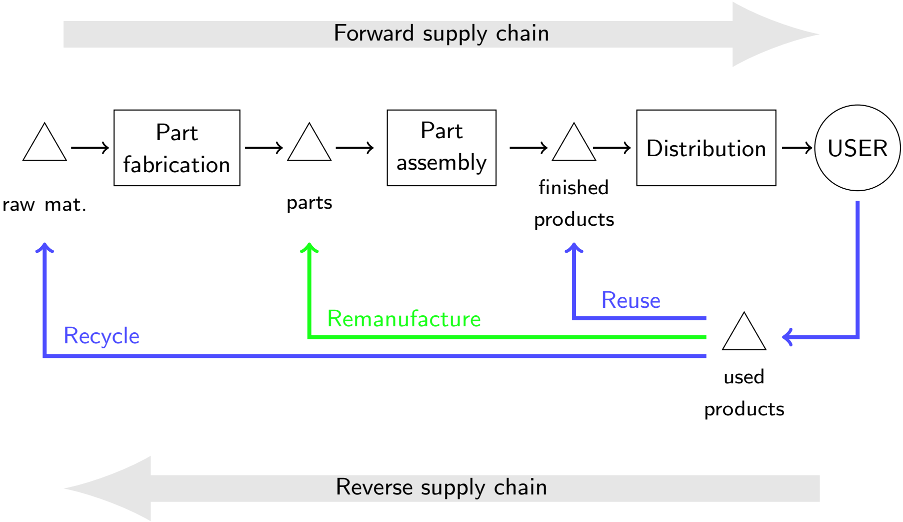
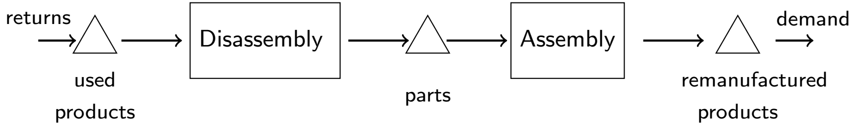


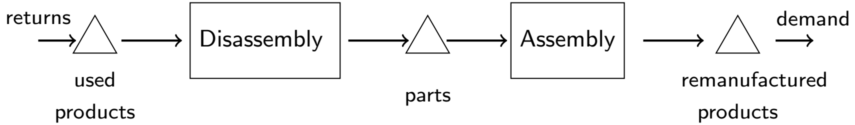
Remanufacturing planning

Remanufacturing system



Remanufacturing planning

Remanufacturing system



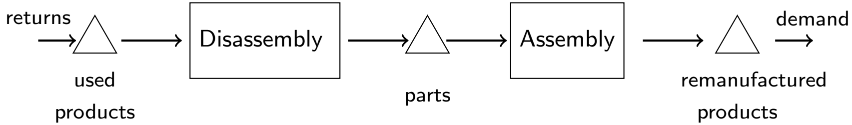
Aggregate production planning

Decide how many:

- used products to disassemble
- remanufactured products to assemble

Remanufacturing planning

Remanufacturing system



Aggregate production planning

Decide how many:

- used products to disassemble
- remanufactured products to assemble

so as to:

- satisfy customer demand
- respect technical constraints: capacity, bill of materials, inventory balance
- minimize total production costs.

Uncertain returns/demand

A specific feature in reverse logistics

No binding agreement with the end users to manage product returns

Lack of control on the product returns quantity and quality

$\rightarrow$ High level of uncertainty in the input data of the optimization problem

[Fleischmann *et al.*, 1997]

Uncertain returns/demand

A specific feature in reverse logistics
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[Fleischmann *et al.*, 1997]

Our proposal
A two-stage stochastic programming approach to take into account the uncertainty on:

- returns quantity / quality
- customer demand

Plan

Overview of the literature

Aggregate production planning for remanufacturing

- General literature reviews
  [Aksali and Cetinkaya, 2011] , [Lage and Godinho, 2012]
- Deterministic optimization problems
  [Jayaraman, 2006] , [Qu and Williams, 2008]
  [Corominas *et al.*, 2012] , [Fall *et al.*, 2013] , [Han *et al.*, 2013]
- Stochastic optimization problems
  [Li *et al.*, 2009] , [Shi *et al.*, 2010]
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Classification based on

- the production planning problem
- the uncertainty modeling
- the solution approach

Classification (1)

Production planning problem

	Products	Periods	Prod. stages	Activities
Li *et al.*, 2009	1	T	1	Remanuf.
Shi *et al.*, 2010	N	1	1	Manuf./Remanuf.
Denizel *et al.*, 2010	1	T	2	Remanuf.
Rouf and Zhang, 2011	N	1	2	Remanuf.
Mahapathra *et al.*, 2012	N	T	1	Manuf./Remanuf.
Our work	N	T	2	Remanuf.

+ A realistic production planning problem
- Focus only on the remanufacturing activities

Classification (2)

Uncertainty modeling

	Demand	Returns quantity	Returns quality	Uncertainty representation
Li *et al.*, 2009	x	x		Discrete random variables
Shi *et al.*, 2010	x	x		Continuous random variables
Denizel *et al.*, 2010			x	Scenario tree
Rouf and Zhang, 2011	x	x		Continuous random variables
Mahapathra *et al.*, 2012			x	Deterministic
Our work	x	x	x	Scenarios

+ Uncertainty on demand / returns quantity / returns quality
- Simple representation via a set of discrete scenarios

Classification (3)

Solution approach

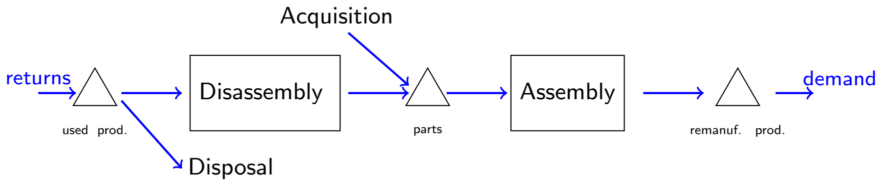
	Backlog Lost sales	Probabilistic constraints	Recourse actions	Solution approach
Li *et al.*, 2009	x			Stochastic dynamic prog.
Shi *et al.*, 2010	x	x		Single-stage stoch. prog.
Denizel *et al.*, 2010			x	Multi-stage stoch. prog.
Rouf and Zhang, 2011	x	x		Single-stage stoch. prog.
Mahapathra *et al.*, 2012			x	Recourse problem only
Our work	x		x	Two-stage stoch.prog.

+ Definition of recourse actions applicable in practice
- Consideration of only 2 stages in the decision process

Plan

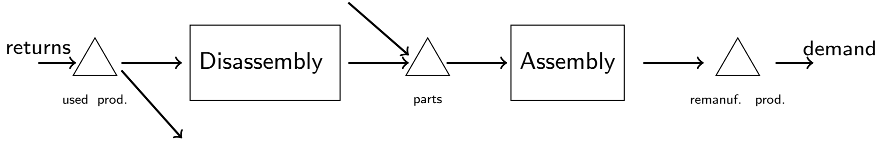
Problem description (1)

Product flows



Problem description (3)

Main decisions



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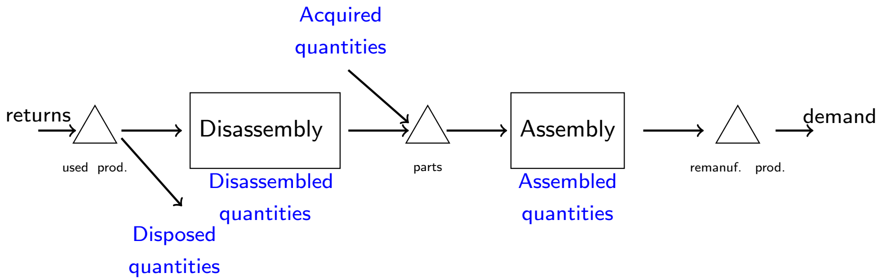
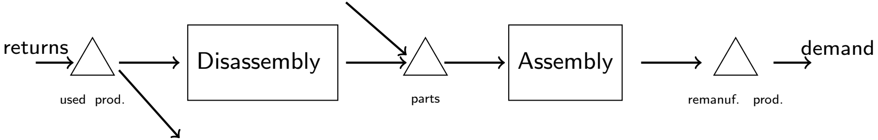


Problem description (3)

Constraints



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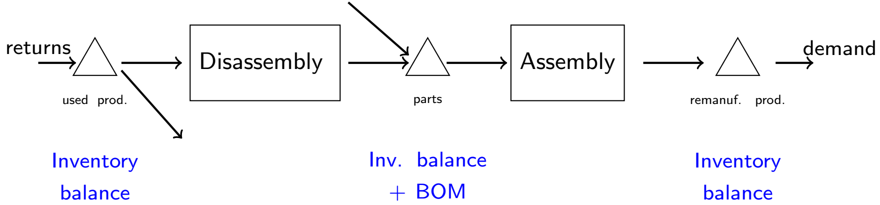

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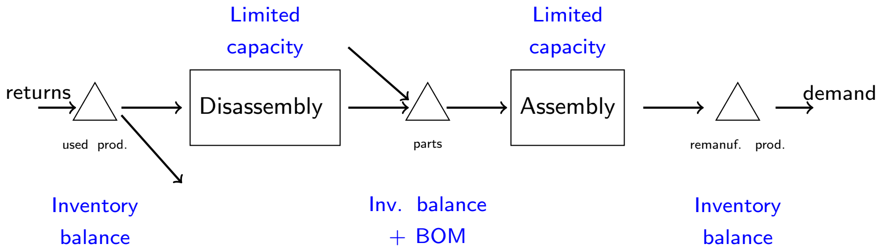
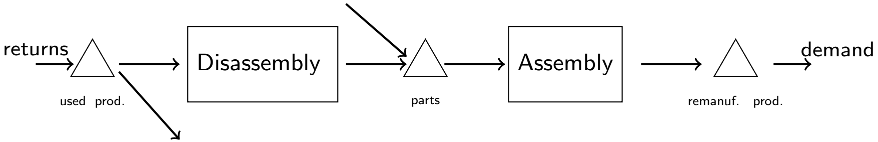


Problem description (4)

Costs



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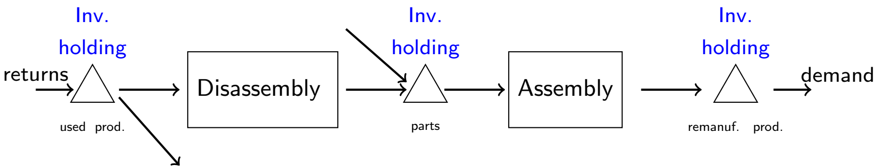

Problem description (4)

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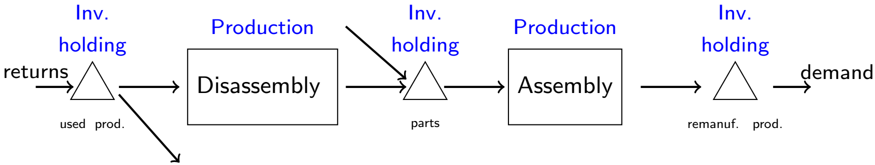

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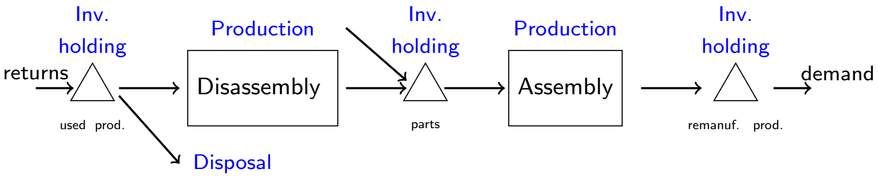

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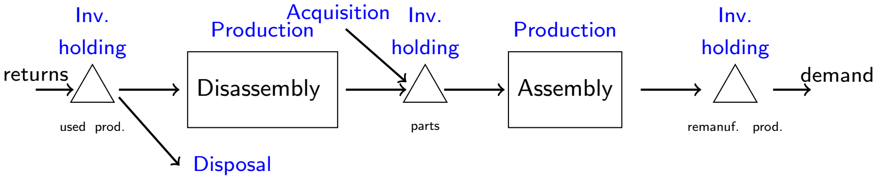


Problem description (5)

Quality of the returned products

Use of a finite set of discrete quality levels

For each returned product type and each quality level:

- A disassembly bill-of-material
- A per unit disassembly capacity consumption
- A per unit disassembly cost

[Jayaraman, 2006]

Assumption

The returned products have already been sorted and assigned to a quality level.

Linear programming formulation

Minimize total production costs

= disassembly/assembly costs

\+ inventory holding costs

\+ new parts acquisition costs

\+ used products disposal costs

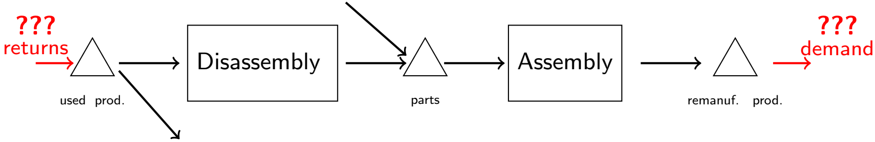
subject to :

- capacity constraints
  - disassembly
  - assembly
- inventory balance + BOM constraints
  - returned products
  - parts
  - remanufactured products

Plan

Uncertainty

Uncertain input data



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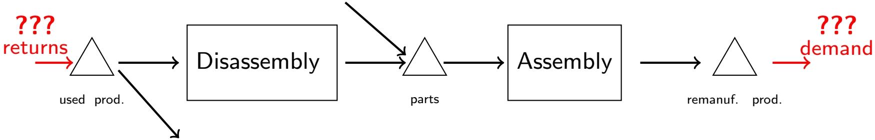

Consequences

- Demand
  $\rightarrow$ Impact limited to the remanufactured product inventory

Uncertainty

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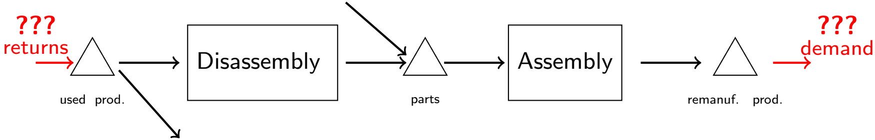


Consequences

- Demand
  → Impact limited to the remanufactured product inventory
- Returns quantity and quality
  → Disorganization of the disassembly and assembly production plan

Uncertainty representation

Continuous random variables

- Uncertainty mostly due to forecasting errors
- Forecasting errors = Normally distributed random variables
- Terms involving integrals in the mathematical formulation
- $\rightarrow$ Computational difficulties

Uncertainty representation

Continuous random variables

- Uncertainty mostly due to forecasting errors
- Forecasting errors = Normally distributed random variables
- Terms involving integrals in the mathematical formulation
- → Computational difficulties

A finite set of discrete scenarios

- Monte Carlo sampling of the continuous random variables
- A scenario = a possible realization of all uncertain parameters

  For each period:
  - demand for each remanufactured product
  - returned quantity for each quality level of each used product
- The larger the sample size, the better the approximation.

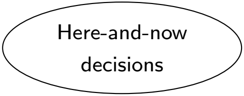
Two-stage stochastic programming approach

A two-stage decision process

Two-stage stochastic programming approach

A two-stage decision process

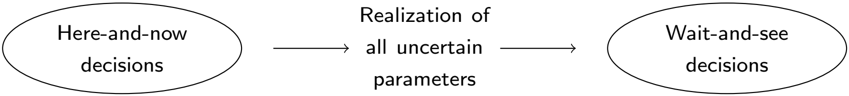
1. "Here-and-now" decisions
   Before the realization of the uncertain parameters
   Decisions common for all scenarios



Two-stage stochastic programming approach

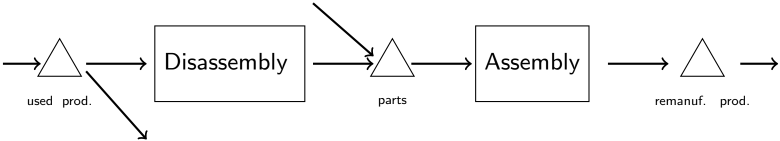
A two-stage decision process

1. "Here-and-now" decisions
   Before the realization of the uncertain parameters
   Decisions common for all scenarios
2. "Wait-and-see" decisions / Recourse actions
   After the realization of the uncertain parameters
   Decisions specific to each scenario



Two-stage stochastic programming approach

First stage decisions



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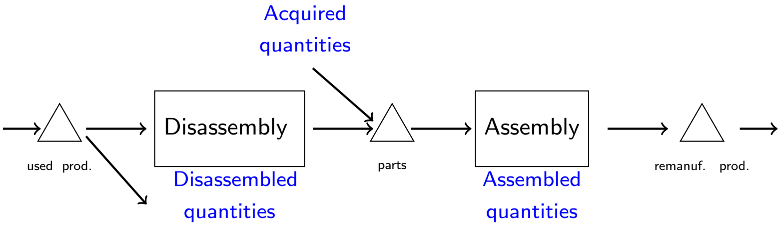
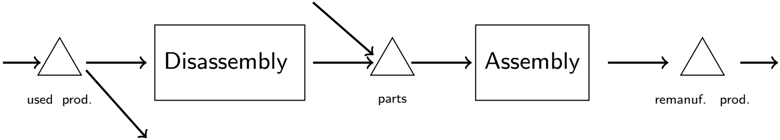


Two-stage stochastic programming approach

First stage constraints



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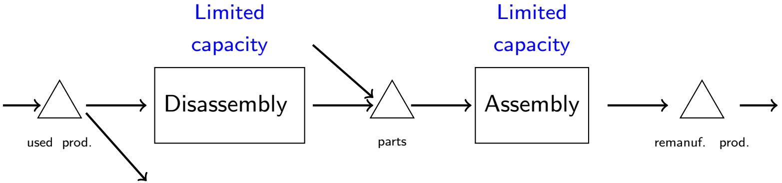
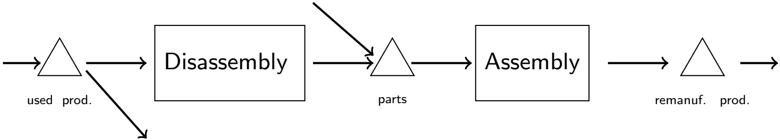


Two-stage stochastic programming approach

First stage costs



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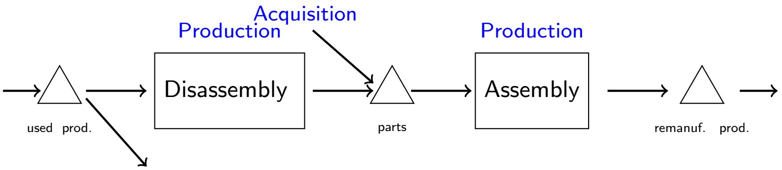
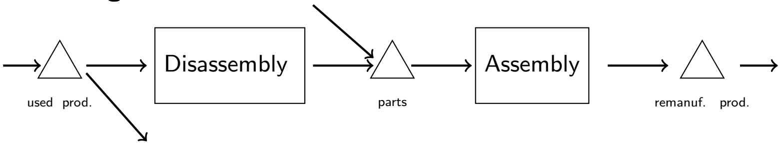


Two-stage stochastic programming approach

Second stage decisions



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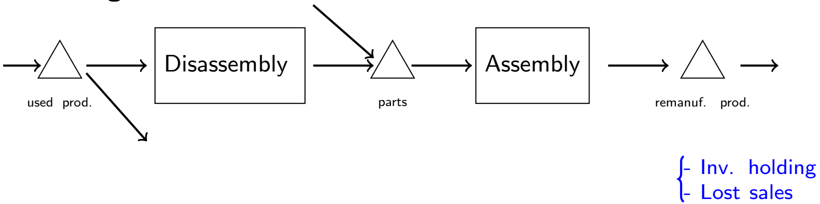

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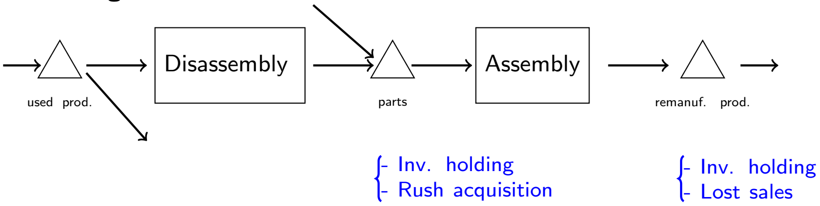

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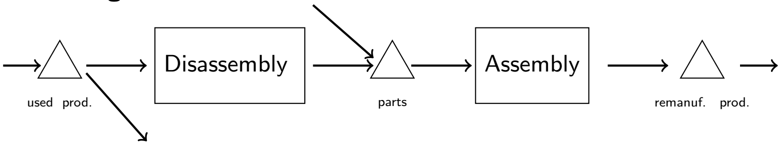


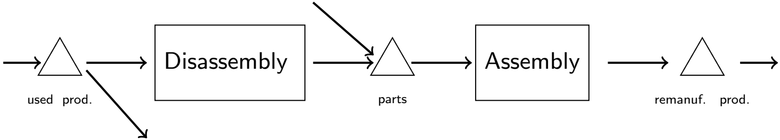
- Inv. holding/Disposal
- Decreased diassembled qty

- Inv. holding
- Rush acquisition

- Inv. holding
- Lost sales

Two-stage stochastic programming approach

Second stage constraints



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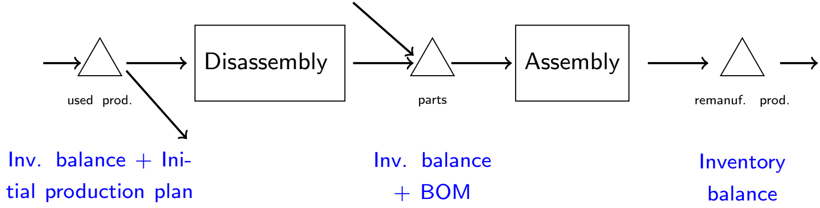

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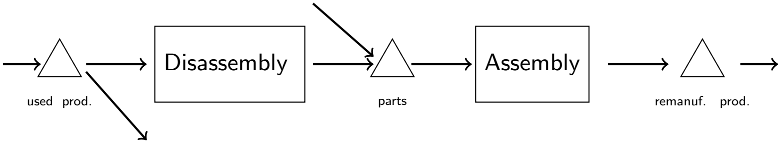

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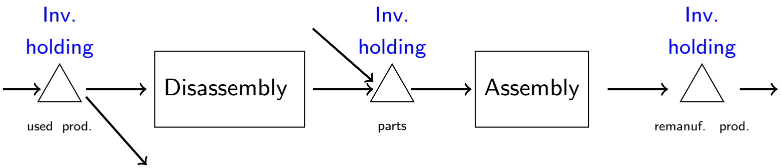

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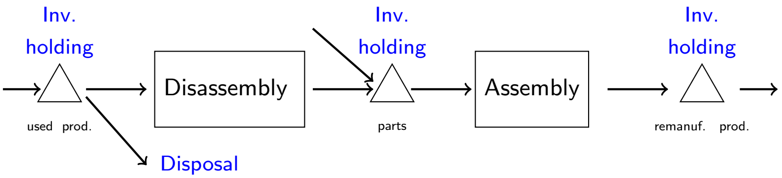

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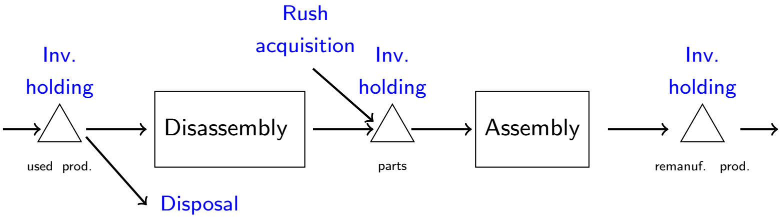

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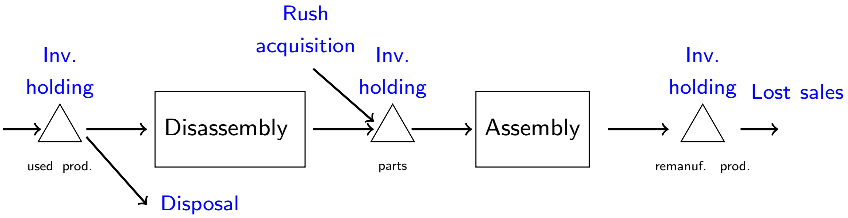

Linear programming formulation

Minimize total production costs

= first-stage decision costs
  - disassembly/assembly cost
  - new parts acquisition cost

\+ expected value of the second-stage decision costs
  - inventory holding cost
  - used products disposal cost
  - new part rush acquisition cost
  - lost sales cost

subject to :

- first-stage constraints
  - disassembly capacity
  - assembly capacity
- second-stage constraints
  - inventory balance of returned products
  - inventory balance of parts
  - inventory balance of remanufactured products
  - link between the initial and adjusted disassembled quantities

Plan

Instances

Instance size

	Used/remanuf. products	Quality levels	Parts	Periods
Instance 1	2	1	1	2

Numerical values of the deterministic parameters

Case study presented in [Jayaraman, 2006]
Remanufacturing of mobile phones

Scenario generation

- Random parameters: uniform probability distribution
- Expected value based on the case study presented in [Jayaraman, 2006]
- Support interval: +/- 10% around the expected value

Preliminary results

Scenarios	Variables	Constraints	Optimal cost
1	11	6	58.8
10	189	135	75.7
100	617	309	243.5
1000	19994	13995	352.7
2000	39994	27995	483.2
2600	_	_	_

Plan

Conclusion

Remanufacturing planning under uncertainty

- Aggregate production planning
- Multi-product multi-period problem
- Disassembly/Reassembly coordination
- Uncertainty on the demand, returns quantity and quality

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- Aggregate production planning
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- Uncertainty on the demand, returns quantity and quality

Two-stage stochastic programming approach

- Uncertainty represented by a set of discrete scenarios
- First-stage decisions: initial production and supply planning
- Second-stage decisions: planning adjustments applicable in practice
- Formulation of a large-size linear program

Perspectives

Short-term perspectives

- Develop a efficient solution approach based on the L-shaped method
- Assess the practical interest of using stochastic programming

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- Assess the practical interest of using stochastic programming

Mid-term perspectives

- Improve the production planning problem representation:
  - more activities: sorting/grading, part refurbishing
  - hybrid manufacturing/remanufacturing system
  - non-linear production costs
- Improve the uncertainty representation
  $\rightarrow$ multi-stage decision process

Thank you for your attention !