EFFIROB

Profitability analysis of new service robotic applications and their means for robotic development

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Fraunhofer IPA Fraunhofer ISI

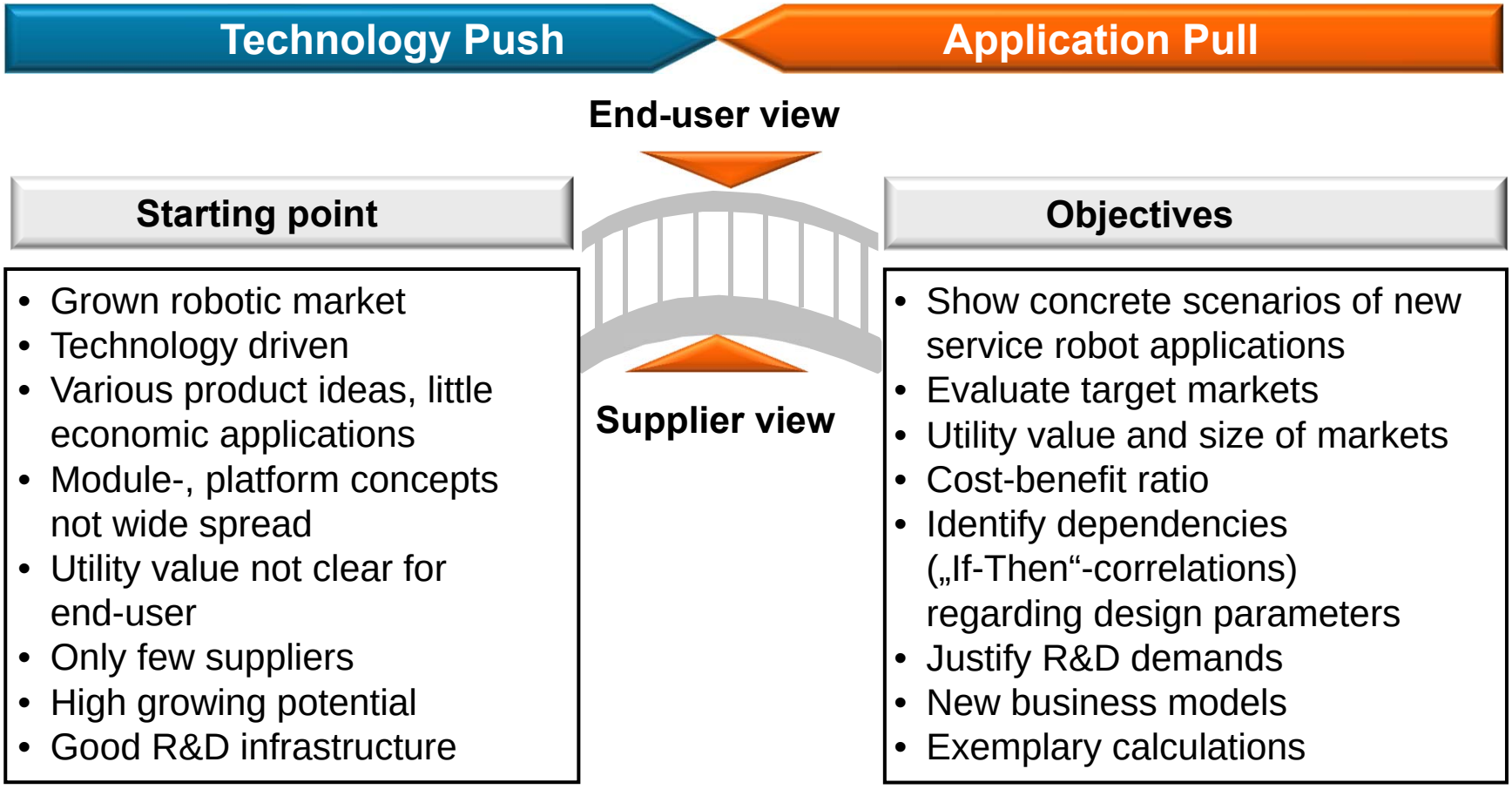
Outline

Introduction	• Motivation • Objectives • Approach • Target markets and scenarios
Methods	• Systems Engineering (AD) • Software Cost Estimation • Life-Cycle-Costing LCC • Market Structure Analysis
Scenarios	• Scenario Descriptions • Example
Conclusion	• Economics, Market Potencial • Safety • Key Components

Motivation

- German Ministry for Education and Research (BMBF) spend over 50 Mio. € for robotics research in the past years.
- Identification of industrial application scenarios for service robotics which are:
  - Already economically feasible → motivate industrial cooperation
  - Close to feasibility → fund projects to overcome borders
  - Not feasible → identify blocking points and fund basic research
- Identification of key components and common parts in service robotic

Objectives of the Study



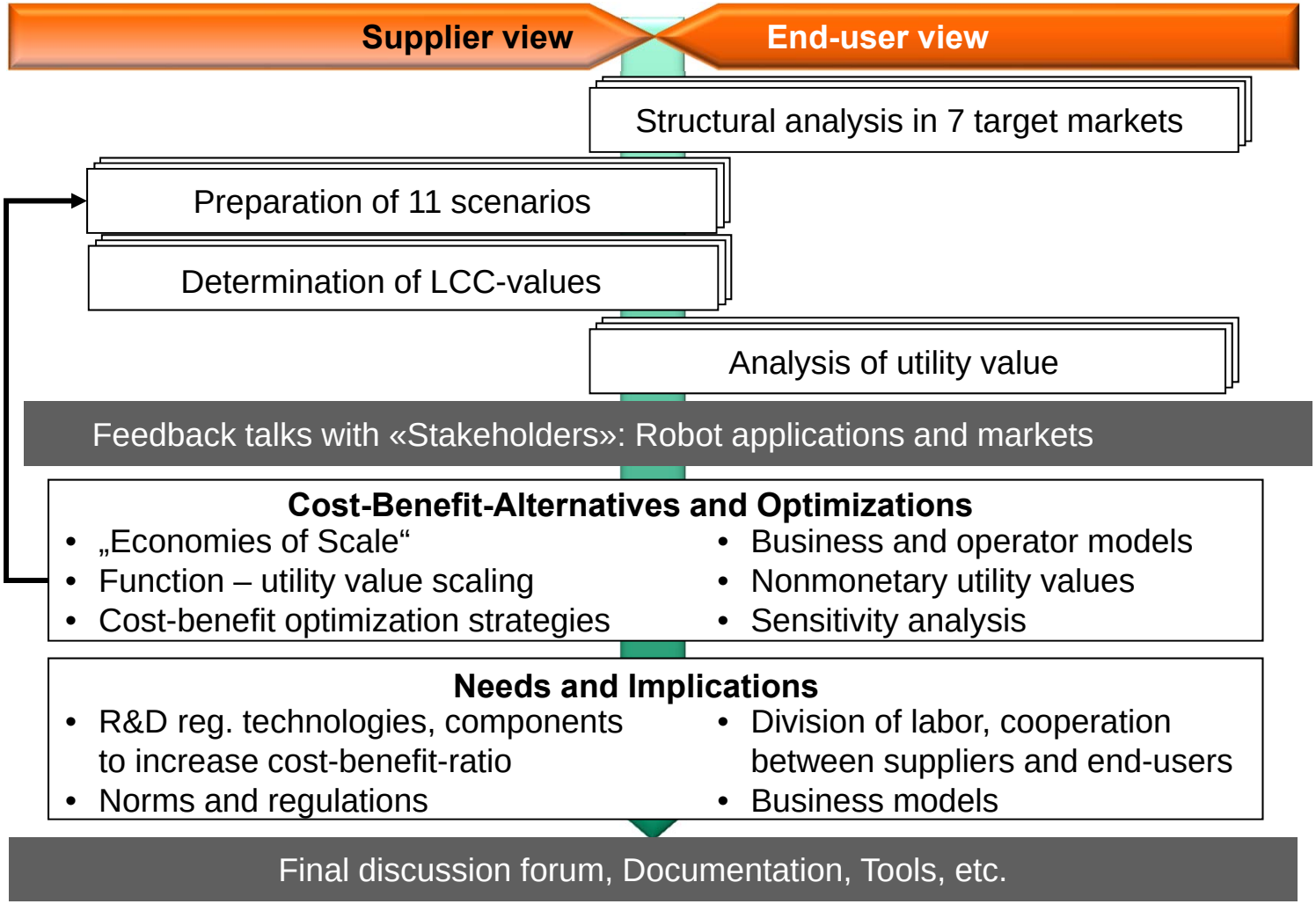
Starting point

- Grown robotic market
- Technology driven
- Various product ideas, little economic applications
- Module-, platform concepts not wide spread
- Utility value not clear for end-user
- Only few suppliers
- High growing potential
- Good R&D infrastructure

Objectives

- Show concrete scenarios of new service robot applications
- Evaluate target markets
- Utility value and size of markets
- Cost-benefit ratio
- Identify dependencies („If-Then“-correlations) regarding design parameters
- Justify R&D demands
- New business models
- Exemplary calculations

Overview: Approach and Methods



Scenario Development

Product ideas

Existing product ideas | New product ideas

Preliminary idea evaluation

- Lot size
- Feasibility
- Supplier industry

viable | partly viable | not viable

- Profitability
- Demand, benefit
- Culture

Development of scenario solution

Estimation of economic characteristics

- LCC
- Economies of Scale
- Sensitivity analyses

- Market structure
- Exploitation of market potential
- Demand, benefit

Scenario fact sheet

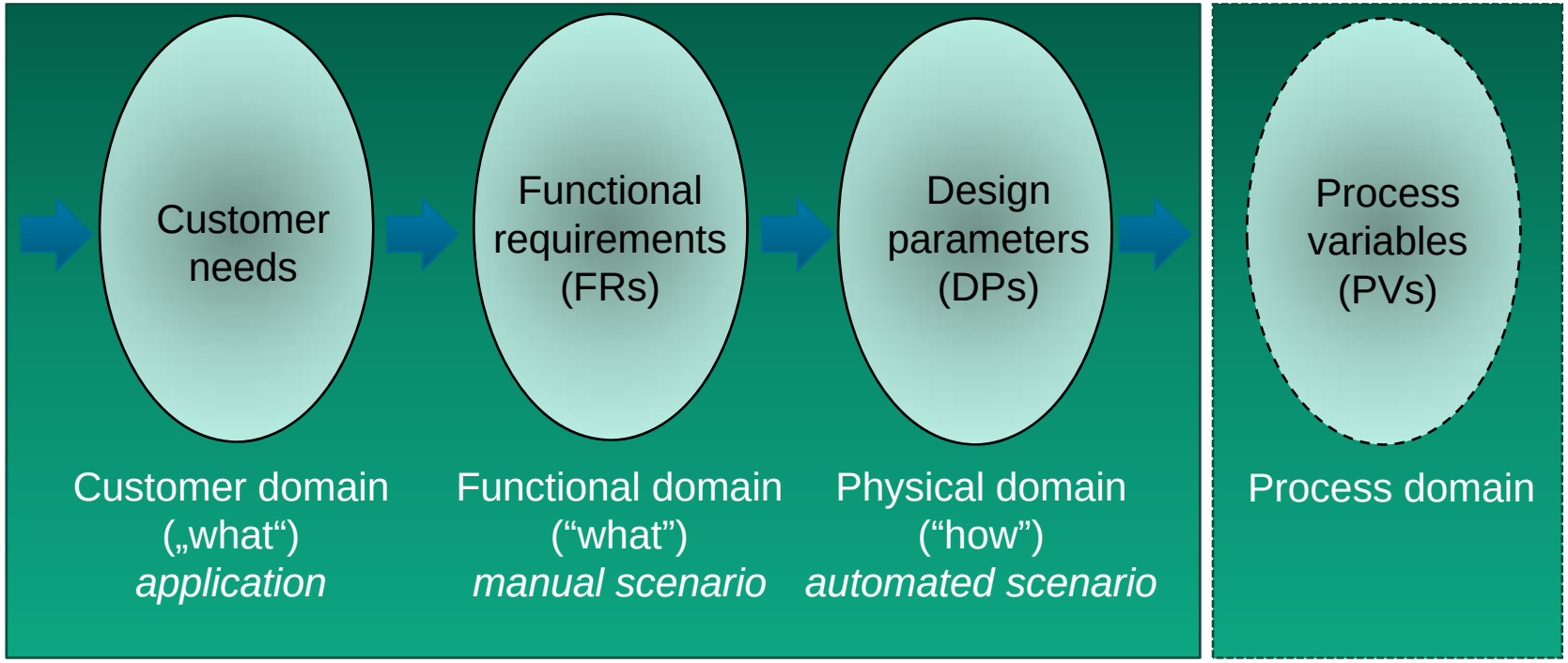
Technical characteristics	Economic characteristics
Brief description of sector	Production costs, unit cost elasticities
Scenario requirements	Installation & operational costs
System concept	Quality & performance comparisons

Target markets and applications

Target market	Application
Agriculture	Ground-crop harvesting
	Dairy cattle farming
Energy and water supply	Grounds maintenance
	Sewer inspection
Logistics	Container transport in hospitals
Manufacturing	Production assistance
Facility management	Floor cleaning
	Facade cleaning
Construction industry	Interior fittings assistance
Residential and nursing homes	Provisioning of care utensils
	Lifting and moving of persons

Axiomatic Design

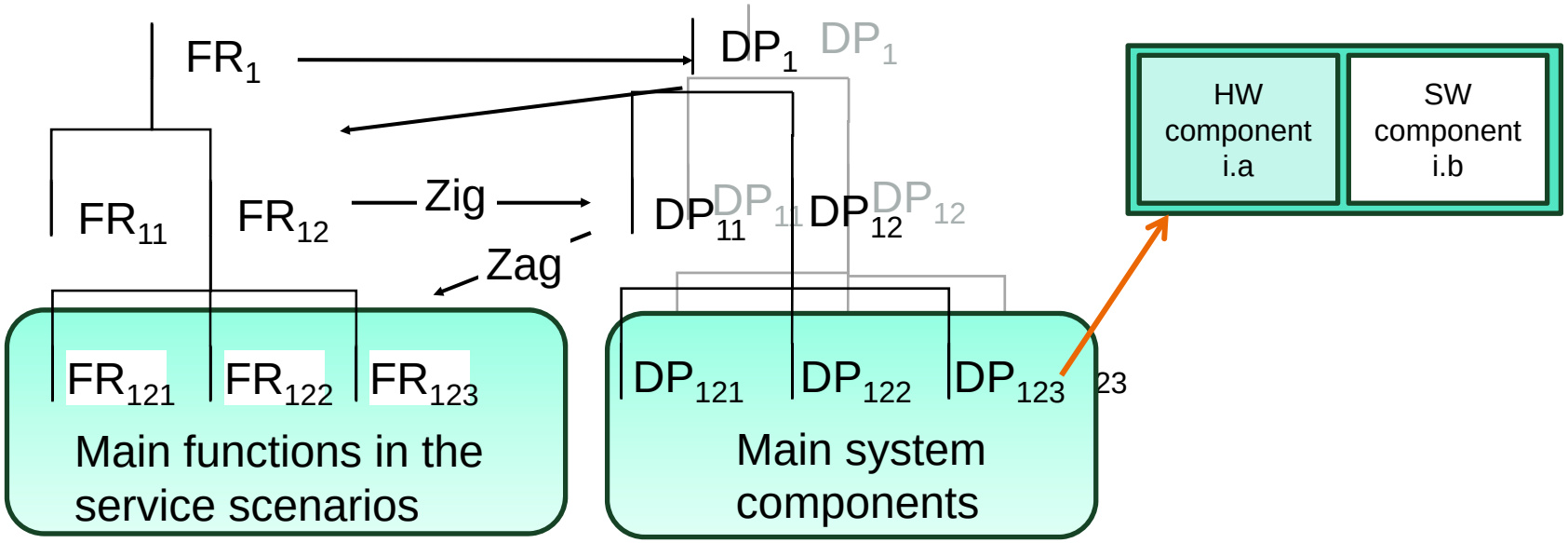
Domains and rules



Axiom 1: Decoupling of functional requirements (from user’s perspective)
→ Decomposition und modularization FR_i→DP_i

Axiom 2: Minimization of information content of the design
→Estimation of functional performance by proposed solution

Decomposition und modularization $FR_i \rightarrow DP_i$



Example: {flow rate, temperature} = | X X | {left valve, right valve}

= | X 0 | {left valve, right valve}

Component catalog hardware (Example: Sensors)

Kriterium	Berührungsfrei messende Sensoren							
Technologie / Reflexion	Laser			Optisch			Ultraschall	Radar
Dimensionen	1D	2D	2,5 / 3D	1D	2D	3D	1D	1D
Detektion	Punkt-Abstand	Linienprofil	Linienprofile/ Flächenprofil	Abstand	ebenes Bild	räumliches Bild	Flächen-Abstand	Abstand, Geschwindigkeit
typ. Erfassungsbereich [m]	typisch < 15	< 80	< 200	< 10	5, abhängig von Optik	< 10	< 10	typisch: < 200
Genauigkeit	< 1%	10–50 mm	< 100 mm	1%	abhängig von Optik	< 20 mm	3%	< 0,25 m
Sicherheitsoption	✓	✓	✓	✓			✓	✓
Messrate (typisch)	< 1 kHz	< 0,1 kHz Scanfrequenz	50 Hz Scanfrequenz	< 1 KHz	<200 FPS	50 FPS	10 Hz	10
Kosten [T€]	0,1 – 2	0,3 – 5	50	0,5 – 2	0,5 – 5	1 – 10	0,1 – 1	
Ausführungsbeispiel	Leuze LPS 36	Sick LMS 500	ibeo LUX 8L (Prototyp)	Balluff BOD 63M	Kappa Kalypso 023-USB	Mesa SwissRanger SR4000	Microsonic CRM +	ContiARS 3XX
								

„Component catalog“ of SR software

Proxy-based estimation using ROS stack list

	FUNCTIONS								
	interactive				internal				function points
ROS stack	Navigation	Manipulation	Perception	Communication	Modeling	Planning	Learning	[illegible]	
arm_navigation		x				x			69
arm_planning_control		x				x			24
articulation	x	x			x	x			247
camera_drivers			x					x	134
camera_umd			x	x					37
collision_environment	x		x						71
common	x	x	x	x	x	x	x	x	310
common_msgs	x	x	x		x			x	38
communication				x					12

⋮

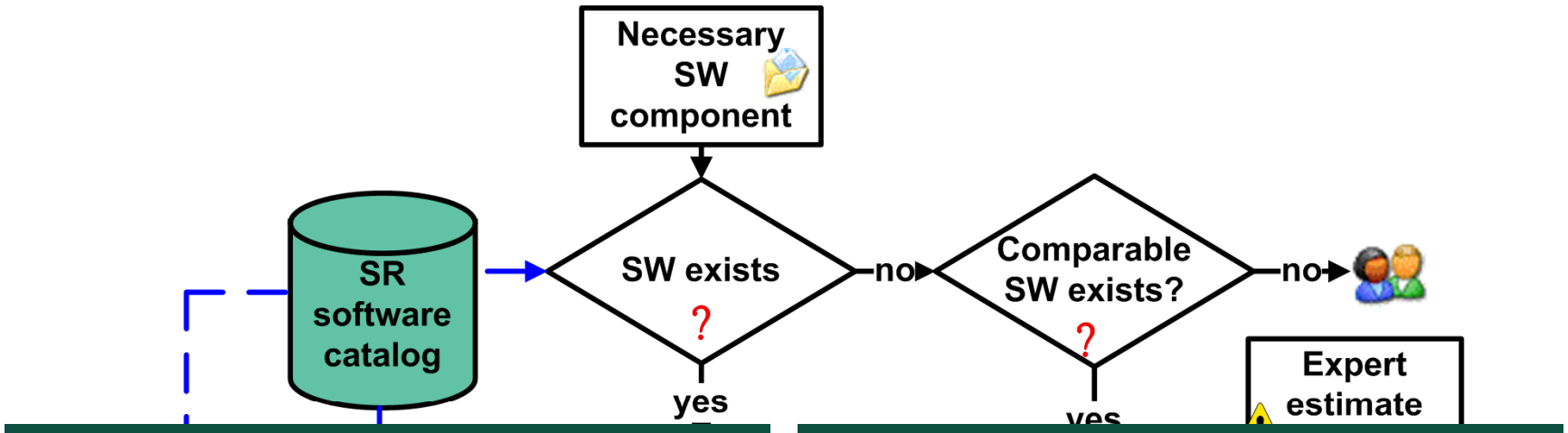
ROS (Robot Operating System by Willow Garage) components used as reference

57 software stacks included in catalog

Function points: Quantitative measure of the functional extent of a software component

Function point counts in catalog were established by code analysis and „backfiring“.

Cost estimation for software development



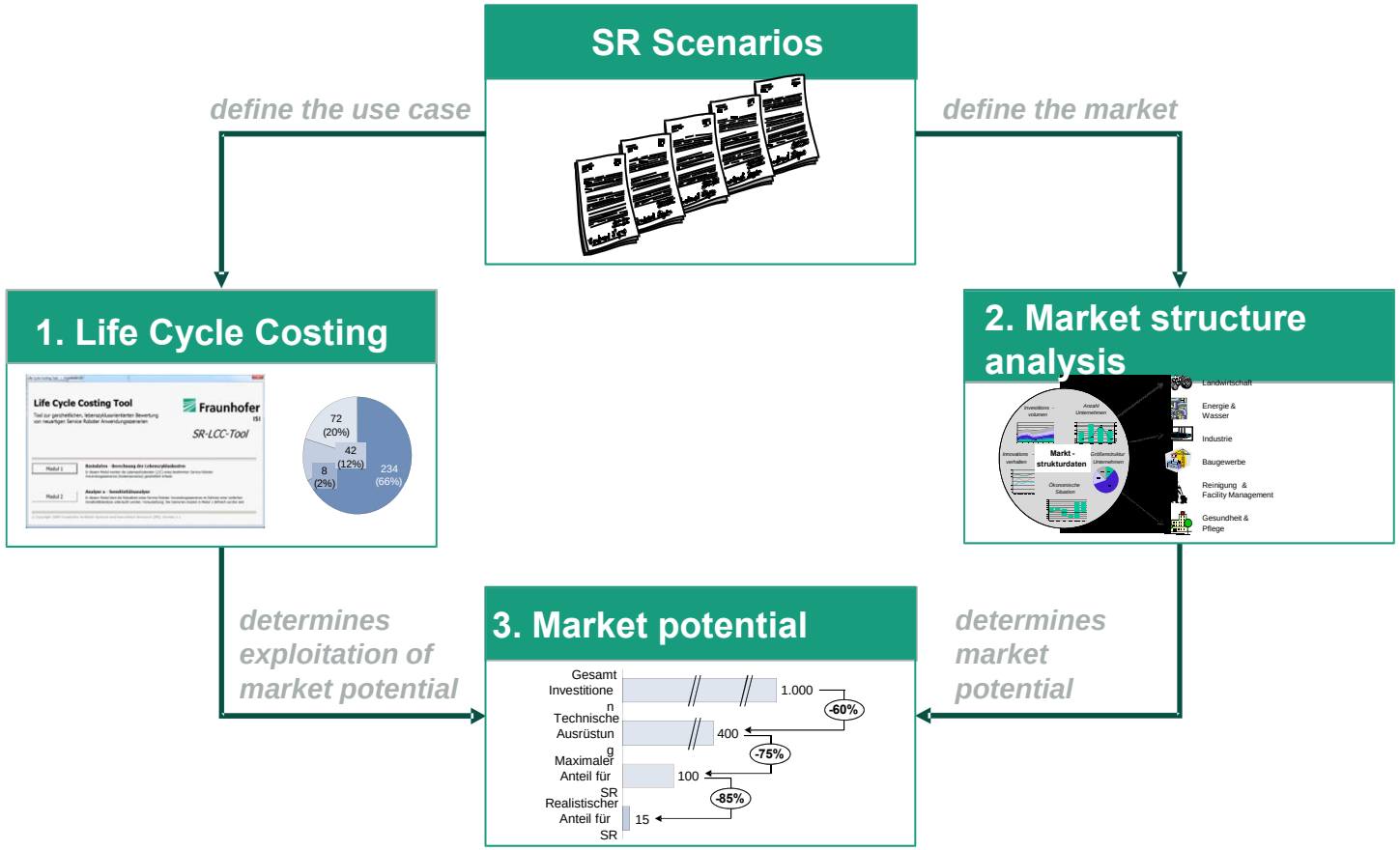
60% reuse, 40% proprietary development

$C_{SW} = 0{,}06 * C_{PM} * \sum FP$

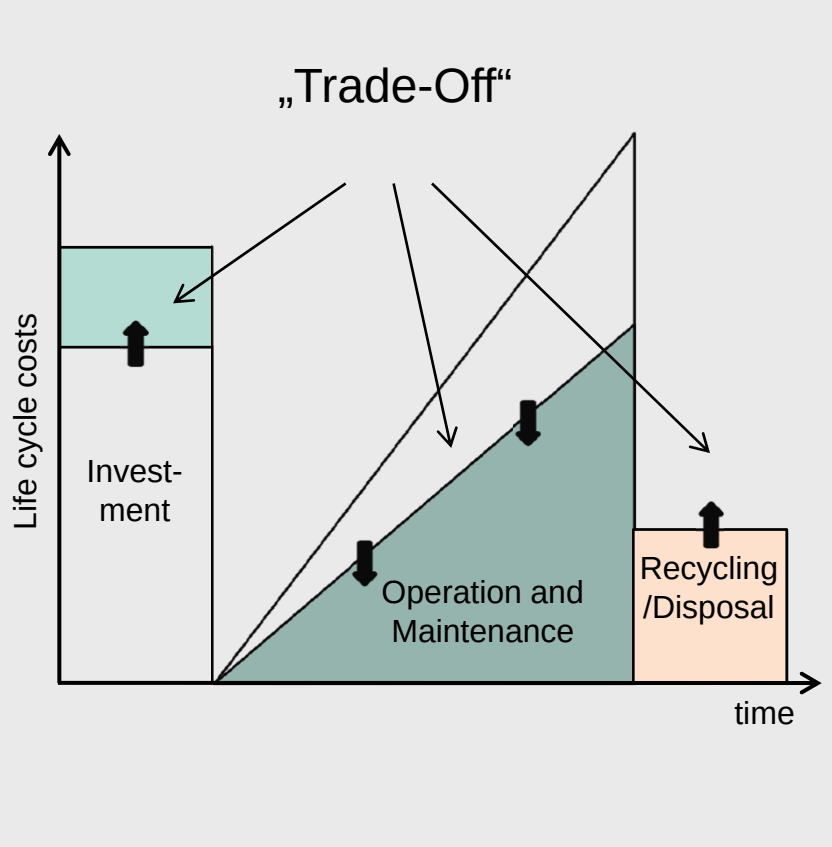
100% proprietary development

$C_{SW} = 0{,}167 * C_{PM} * \sum FP$

Profitability analysis



Why LCC-Analysis?



PROBLEM

- Classical multi periodic decision making instrument
- Bigger part of decision relevant costs incur after buy

→ Cash flow and life cycle orientated consideration

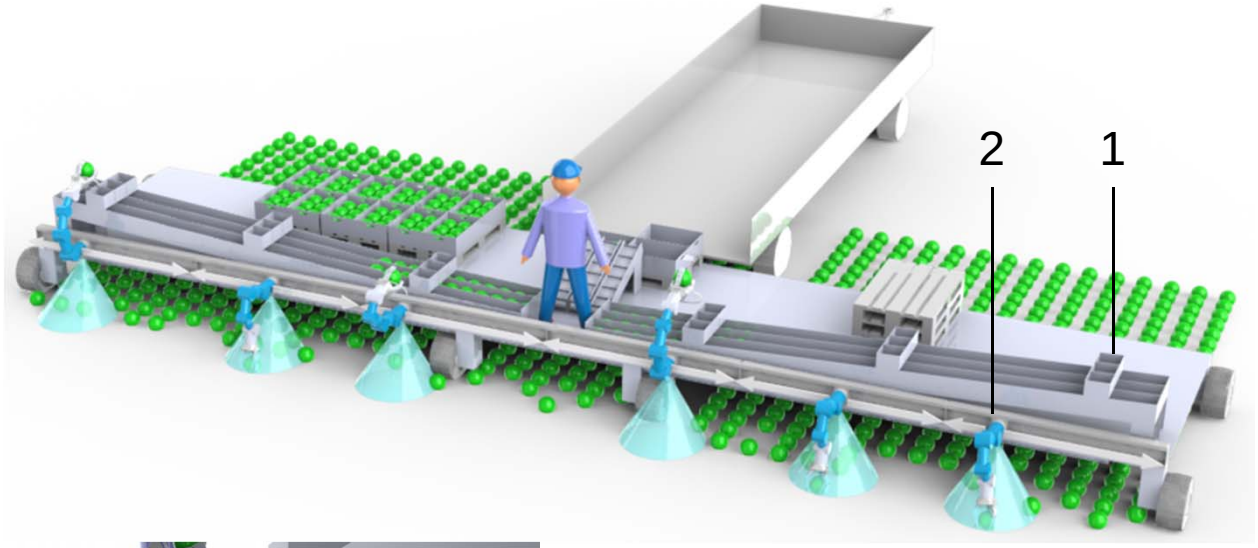
BASIS FOR DECISION

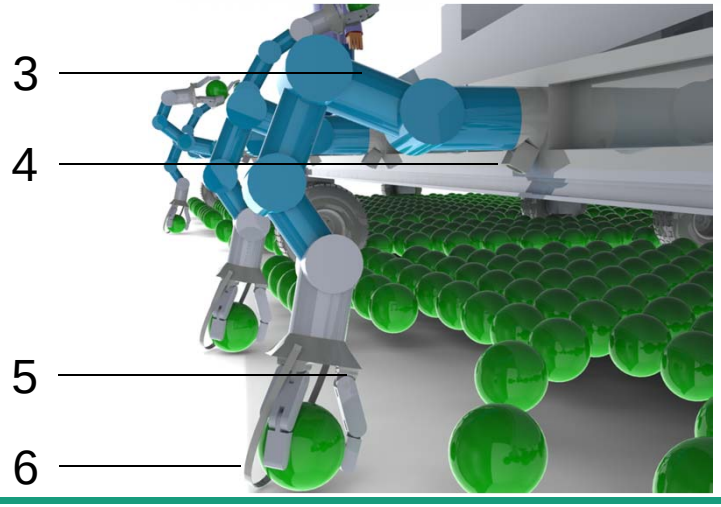
- Absolute amount of LCC
- Amortization time
- Discounted Cash flow
- Cost per activity unit

Scenario Ground-crop Harvester: Manual Solution

- 12 meter wide harvesting beam
- 12 harvesters
- 12 classifiers
- 3 packers
- 1 group leader

Scenario Ground-crop Harvester: SR concept





1 Packing unit

2 Robot on linear axis

3 Robot arm

4 Sensor for object detection

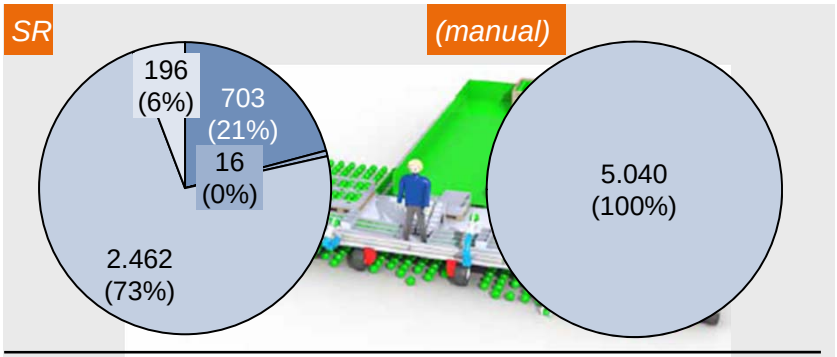
5 Gripper (fruit safe)

6 Cutting unit

Example: Szenario-Comparison

Investment
Installation costs
Activity costs
Mainenance, Service costs

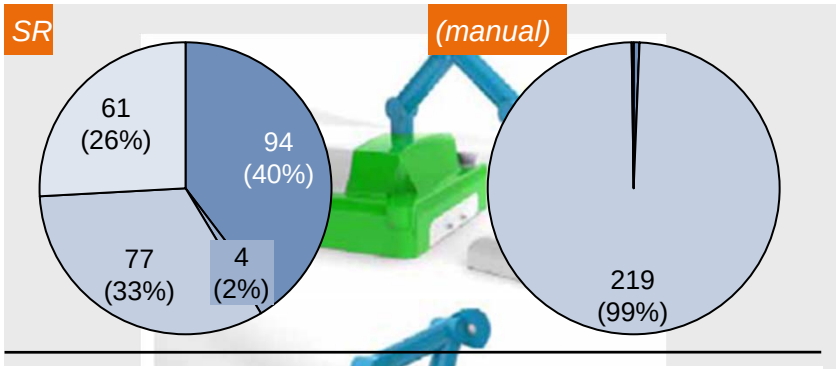
Ground-crop Harvester



LCC-Sum (TEUR)	Cost rate (EUR/#)	DCF (TEUR)	Amortization (years)
3.376,9 (5.040,0)	0,04 (0,04)	-2.763,7 (-3.821,1)	<<3

- Robust result
- Interesting in case of loan increase
- Complete use of market potential expected

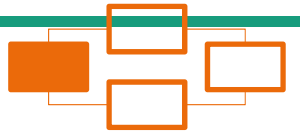
Floor cleaning



LCC-Summe (TEUR)	Cost rate (EUR/#)	DCF (TEUR)	Amortization (years)
234,9 (220,4)	21,51 (15,13)	-193,0 (-153,6)	entfällt

- Even cheapest SR variant more expensive
- Potential just by reduction of investment (>50%) and better use of capacity
- Low market potential

Example:
Economics Analysis Result

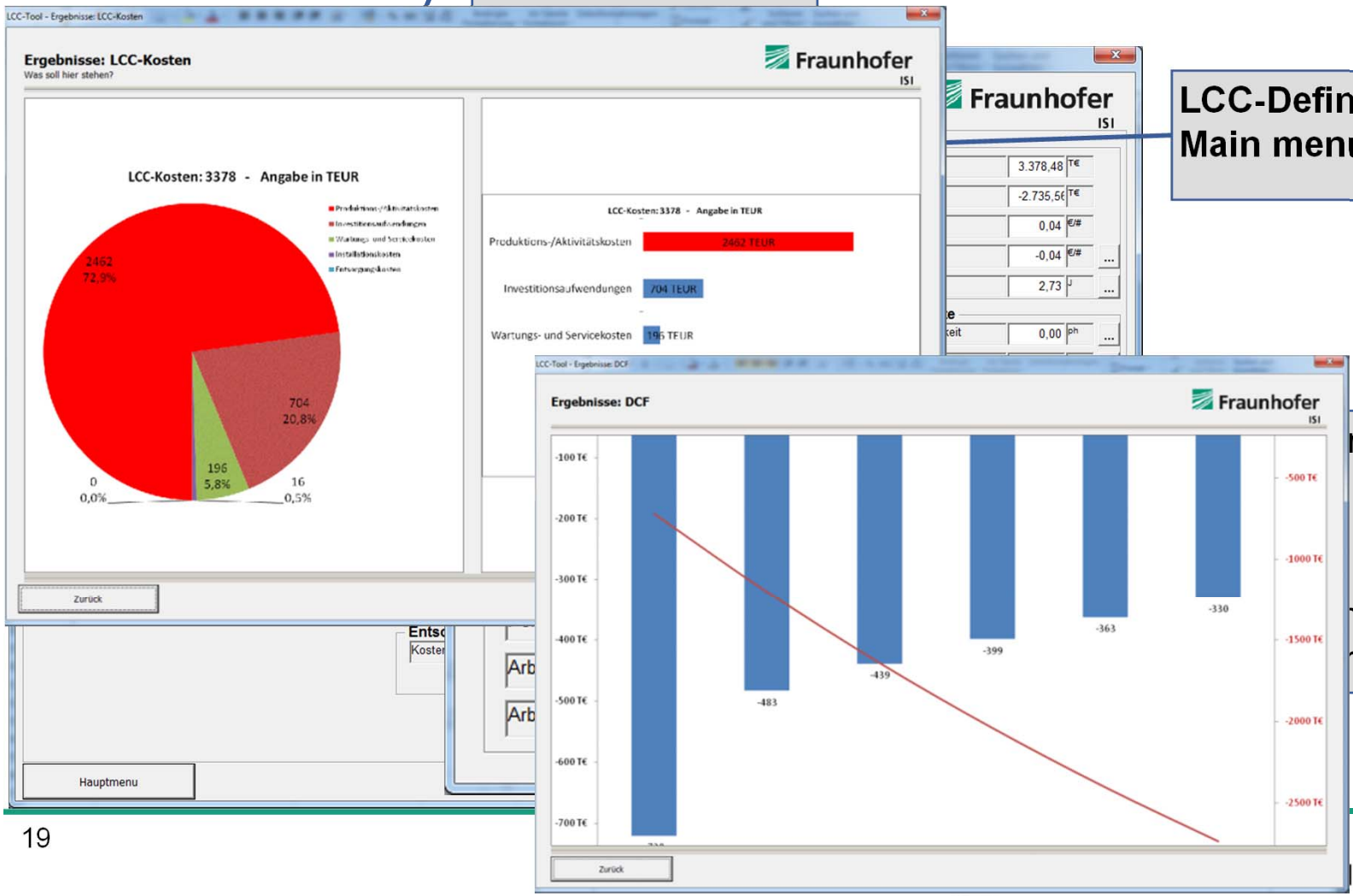


Figures	SR-Version A		SR-Version B		Manual Version	
Basic Data Use Case						
▪ Life time (a)	5		5		5	
▪ Number of Robots (System)	6		6		-	
▪ Eff. Productive time (h/a)	3.600		3.600		4.560	
▪ Personell time (h/a)	14.400		14.400		134.400	
▪ Activity units (Mio AU/a)	18,1		18,1		23,0	
LCC-Sum (T€)	3.378,5	100,0%	2.871,6	100,0%	5.040,0	100,0%
▪ Investment (T€)	704,1	20,8%	297,2	10,3%	-	-
▪ Installation costs (T€)	16,0	0,5%	16,0	0,6%	-	-
▪ Activity costs(T€)	2.462,4	72,9%	2.464,1	85,8%	5.040,0	100,0%
▪ Maintenance (T€)	196,0	5,8%	94,3	3,3%	-	-
▪ Other	-	-		-	-	-
DCF (@10%, T€)	-2.735,6		-2.253,9		-3.821,1	
Software costs (T€)	903,1		2.994,9		-	
Activity unit costs (€/LE)	0,04		0,03		0,04	

SR-LCC Tool – Screenshots

Scenario-Management:

Scenario selection from database

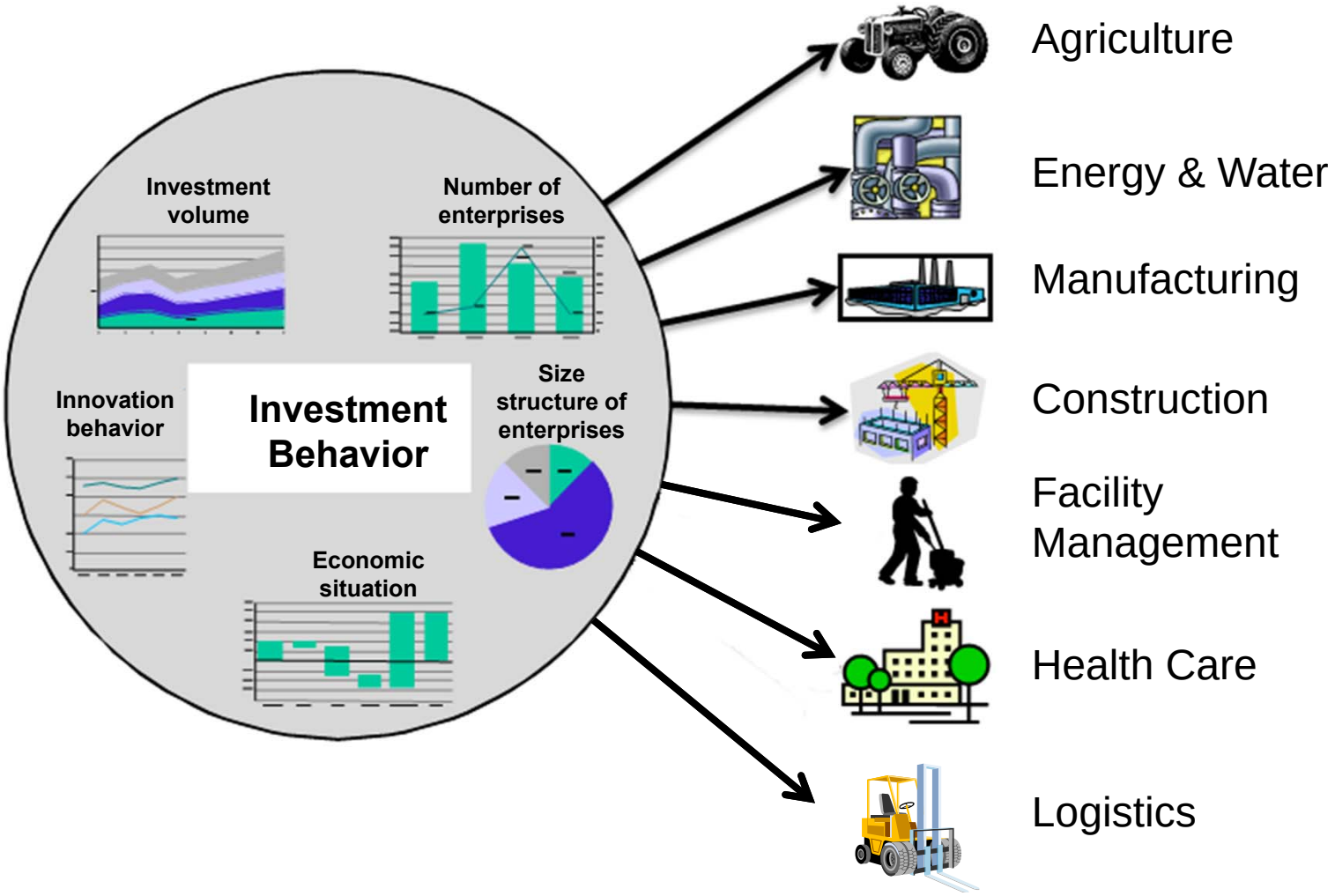


LCC-Definition: Main menu

nition:

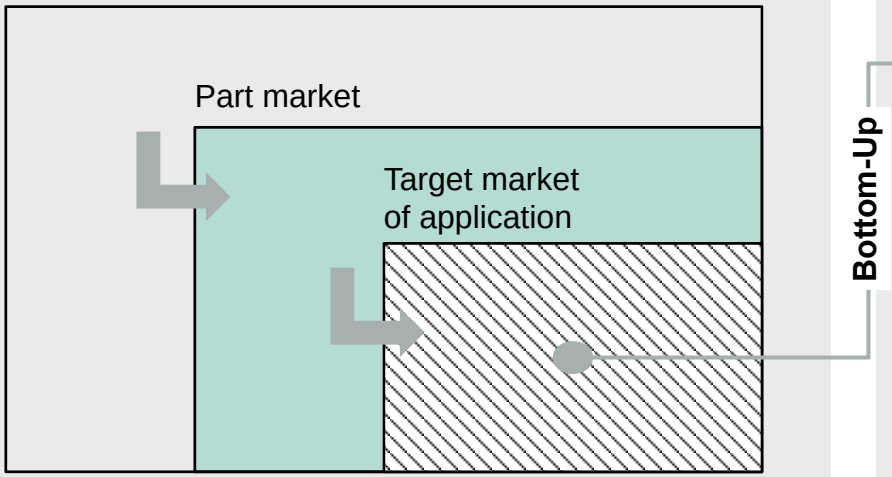
n of
rs

Market structure analysis



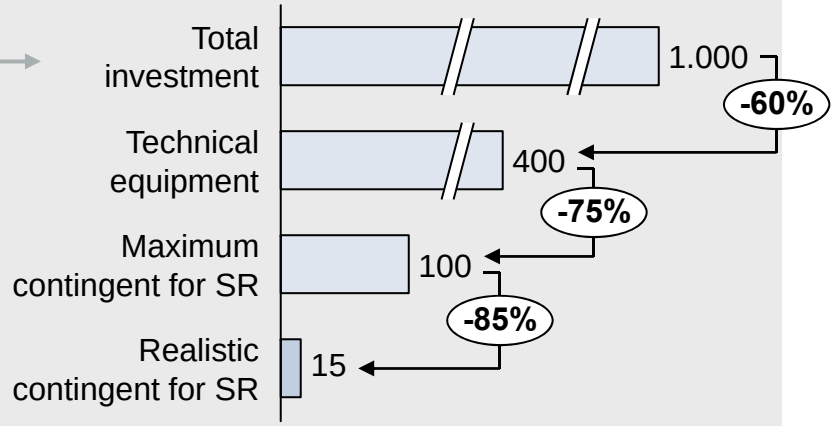
Estimation of market potential

Identify basic population
Businesses



1. Identify basic population (Top-Down)
2. Estimate total investment (Bottom-Up)

Estimation of funds available for SR
TEUR p.a.

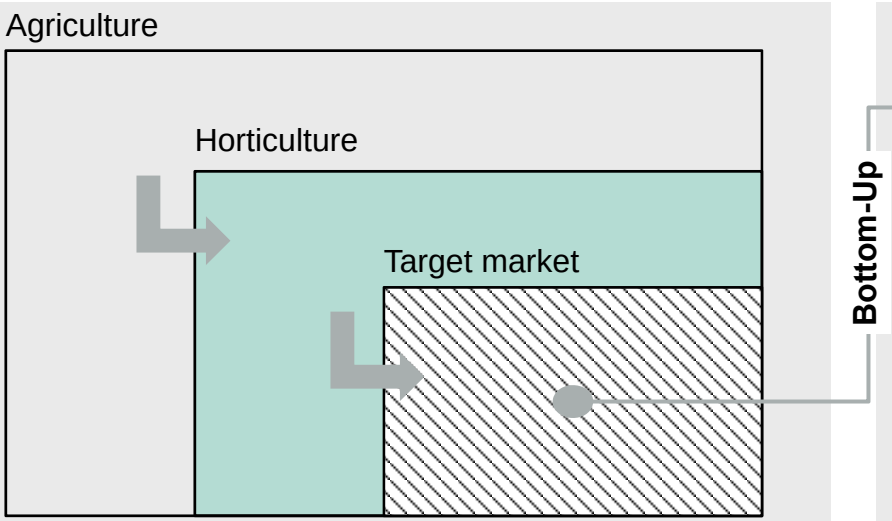


3. Estimate maximum market potential (Top-Down)
4. Estimate realistic exploitation of market potential

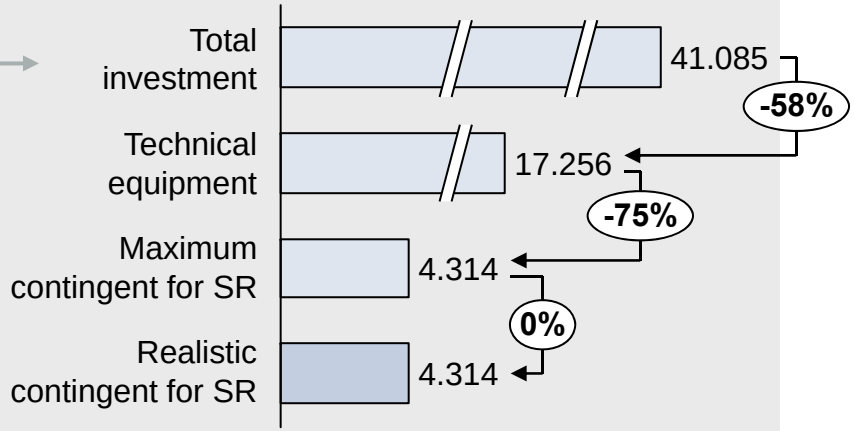
Estimation of market potential
Example: Ground-crop harvester

Identify basic population
Businesses

Estimation of funds available for SR
TEUR p.a.



Bottom-Up



Farms	374.514
thereof horticulture	12.153
thereof vegetables	2.021
thereof in target market (main business, > 30 ha)	316

Market potential for SR	
Sales p.a. *(@ T€ 704,1 / 310,2 per system with 6 SR)*	36 / 84
Expected Installed Base *(@ 5 years life span)*	180 / 420

Service Robot Scenarios

Scenario	Estimates SW-costs/ Scenario [M€]	Economic feasibility		Estimated market potential in SR p.a. for Germany	
		Based on LCC	Relevance of qualitative factors	Calculated maximum	Realistic exploit
Grounds maintenance	1,5	(no)	high	391	39
Provisioning of care utensils	6,8	(no)	high	5 - 10	2 - 5
Lifting and moving of persons	5,0	no	high	6	0
Ground-crop harvesting	0,9	high	low	36 - 84	36 - 84
Floor cleaning	14,0	no	low	25 - 44	0
Container transport in hospitals	3,3	high	high	40 - 60	40 - 60
Facade cleaning	4,2	no	none	3	0
Interior fittings assistance	4,3	high	high	5 - 6	5 – 6
Sewer inspection	0,3	high	high	30 - 59	30 – 59
Dairy cattle farming	4,4	high	high	62	62
Production assistance	4,4	high	low	903 - 1 344	903 - 1 344

Central Findings of the Study (Economics)

Summary

1. *„Reduction of initial investment does not relevantly increase the economic feasibility of a service robot concept: “*
   - Generally < 25 % of LCC → no/low relevance of economies of scale
   - Higher leverage lies in activity and maintenance → Reduction of complexity of use
2. *„A decision relevance of qualitative added value could not be observed at clear negative economics relations:“*
   - Comparable cost positions absolutely necessary
   - Qualitative factors can not change negative economic relations
3. *„Good economic feasibility does not necessarily mean a high exploit of possible market potential:“*
   - Exploit of market potential also limited by means of financing models
   - Some applications call for “new” business models

Critical Claim of the Approach (economics)

ADVANTAGES

+ Holistic and dynamic examination of economic feasibility

+ Mixed estimation of market potential

  - Bottom-Up estimation of potential for investment
  - Top-Down for narrowing down available volume (consideration of market structures and economics)

DISADVANTAGES

- Findings not always reflect real behavior of deciders („Investment cost are after all relevant “)

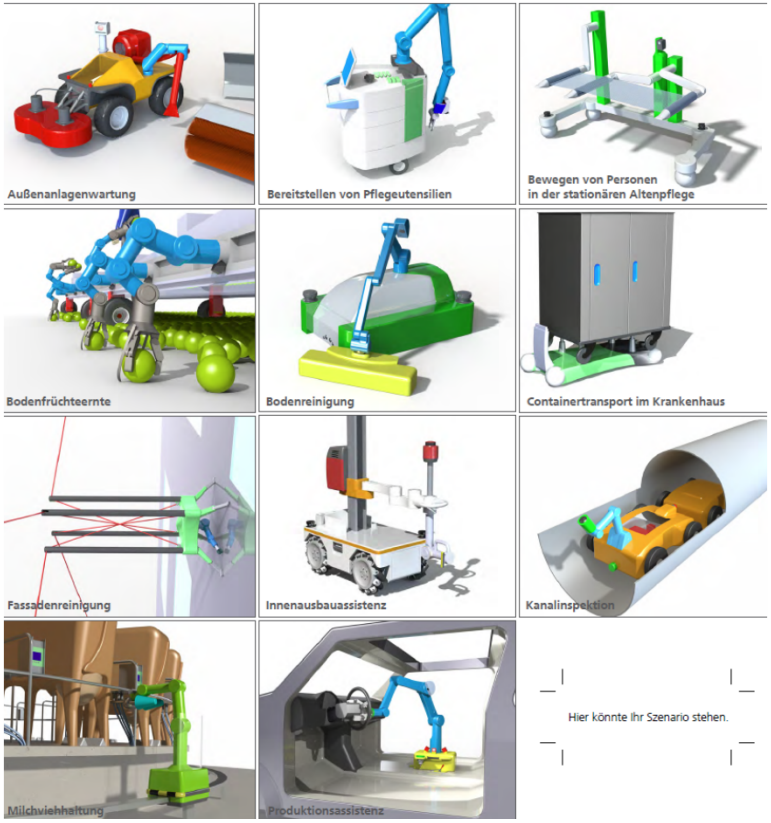
- LCC considerations quite dependent on concrete scenario

Safety

Safety criteria:
- Spatial separation of machine and human
- Avoid shearing and crushing zones
- Safe navigation
- Safe manipulation
- Safe handling of big/heavy objects
- Protection against misuse
- Assurance of stability

Under consideration of:
- Actual and draft ISO Norms
- EU 2006 / 42 / EG

Under assessment criteria:
- Easy to solve
- Solvable
- Solvable under limitations



- Scenarios can be designed “safe”
- Expert knowledge partially necessary
- Sporadically demand for components

Evaluation of used Components and Technologies

4 **Stable base of components** *(at least as prototypes); Effects of former research projects are noticeable.* **Demands:** *High resolution 3D sensors, safety sensors, arm modules with higher payload, flexible grippers…*

5 **Safety-related design of service robots** *based on existing/planed ISO-norms complex but possible*

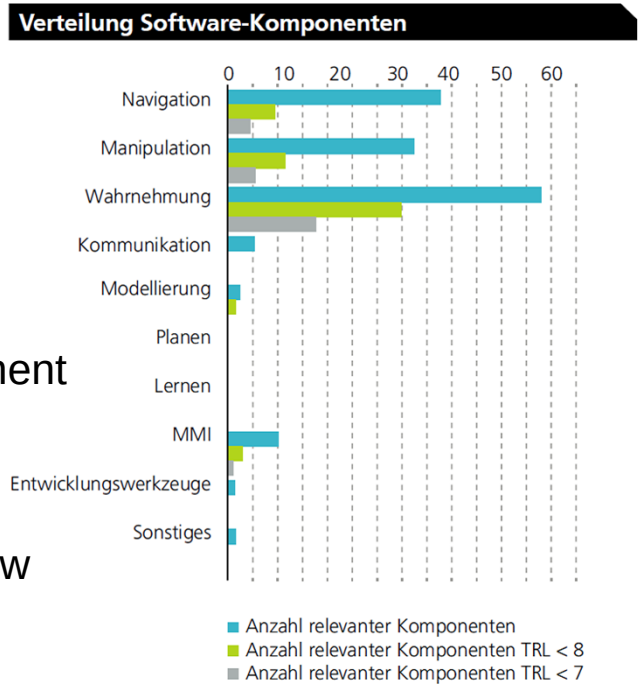
6 **Extensive SW-costs:**

➔ **Re-use**, **plan ability** of SW-components:

- SW-Paradigms (e.g. component based development, model driven engineering, …)
- Repositories for re-usable SW-components
- Standards , guidelines for development and component integration

➔ **Methods for software cost estimation**

- (public) available methods, SW-Controlling know-how



Findings (technically)

7 **Perception** *central and most important basic technology in commercial service robotics. It is connected with other technologies.*

8 **Robustness of key technologie navigation** *suppliers and end-users consider this a central demand (high discrepancy between the rating of the level of maturity of robotic community and suppliers/end-users).*

9 **Key functionality robust grasping** *of spectrums of work pieces and every day objects*

10 **Efficient and safe human-robot-interaction** *improves user acceptance and efficiency* → *Shared Autonomy.*

Possible Impact on Academia-Industry Collaboration

1. **Academia:** Tool to convince industry about economic feasibility of SR solutions
2. **Industry:** Tool to estimate costs for a SR development
3. **Consortia:** Methodology to state expected exploitation
4. **Reviewers:** Comparability of stated exploitations

Interaktiv Document with Software

- Download Study EFFIROB (ZIP, 30MB, 6MB)
- Download LCC-Tool (Excel)
  Download manual
  LCC-Tool (pdf)

http://www.ipa.fraunhofer.de/studien

English printed version planed for

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