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Decision making support to steer offering variety during production planning

by

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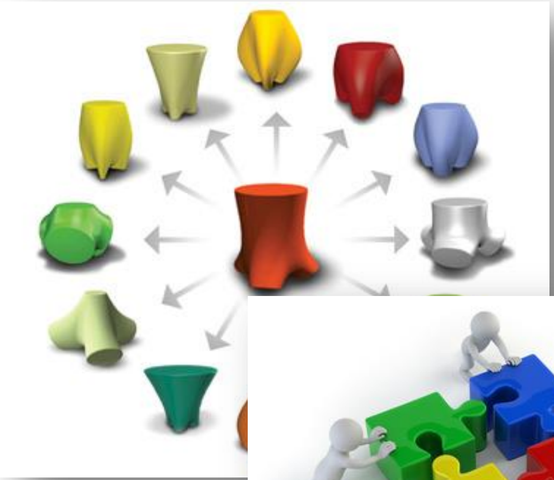
Introduction

Customer requirements and offering variety



- Increasing customers' demands for tailored solutions
- Focus on productivity moves to integration of customer expectations

→ **More variety of the firms offerings!**

- In order to remain competitive, firms struggle to meet customer requirements while reducing costs and impact on environment

→ **Multiple performance drivers and criteria relating to sustainability and variety**

- Need for tradeoffs need to be defined and balanced between such criteria
- Facilitate the decision making process on variety levels with regards to sustainability impact

→ An approach supporting the decision making process on variety of the solutions delivered to the market while taking into account sustainability criteria.

Outline

- What variety level should be delivered to the market?
- Sustainability assessment in operations management
- Variety steering during production planning
- Illustrative example
- Conclusions and research perspectives

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Variety of the offering

What variety level should be delivered to the market?

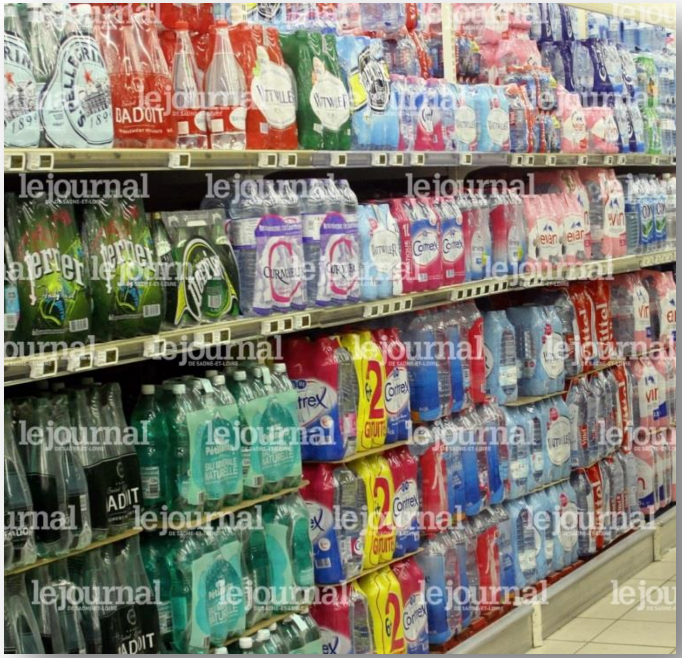
- Increasing product and service variety allows to cope with diversified demands
- Variety is "the **diversity of products** that a production system provides to the marketplace" (Ulrich, 1995)

→ more attractive offering

However…

- Too much variety **confuses customers** (Blecker et al., 2006)
- **Internal complexity:** high number of variants (Samy et al., 2010; Feng et al., 2013)
- Commonality: achieve variety while mitigating complexity (Salvador et al., 2002)

→ Achieve economy of scope while delivering high variety to the market place



Among the most critical questions…

- How many variants should be included in the offering? → **variety management**
- What volume from each variant should be planned? → **variety steering**

→ **Focus of the current research**: take into account sustainability impact of the variants in steering variety

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Sustainability assessment

Sustainability assessment in operations management

Appealing question…

- **Tradeoffs** between environmental and business concerns (Neto et al., 2009; Dekker et al., 2012)
- Commonly addressed aspects include transportation, warehousing, inventory management and reverse logistics (Bloemhof et al., 2011; Wang et al., 2011; Jaegler et al., 2012; Abdallah et al., 2012; Jindal et al., 2013, etc.)

However…

- **Restrictive assumptions** underpinning the proposed optimization models
- **Lack of a life cycle perspective** in green operations optimization (Dekker et al., 2012)

→ Need for preventive measures to reduce footprint and meet customer preferences throughout product life cycle

Recently…

- A **life cycle assessment model** embracing economic, environmental and social sustainability dimensions (Medini et al., 2011; Bettoni et al., 2013)
- Indicators are calculated based on modelling and data extracted from the **Ecoinvent database** (Pedrazzoli et al., 2012)
- High number of **heterogeneous indicators** → need for proper decision making support

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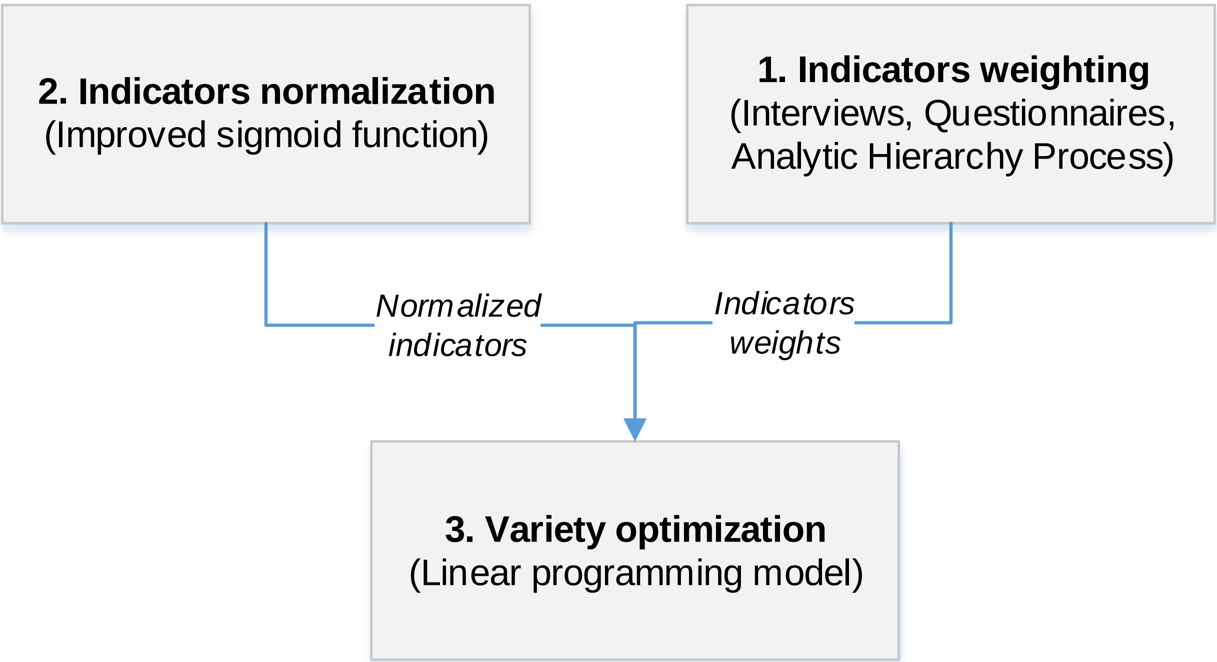
Variety steering during production planning

Methodology

- A decision making supporting approach which considers environmental sustainability criteria and customer demand
- **Balance the production volumes** among different product variants

In a way to…

- **Minimize environmental impact and maximize the profit** generated out of the variants sales.



Variety steering during production planning

Indicators list

A sub-set of the indicators is adopted from (Bettoni et al., 2013) to measure the **economic output** and **environmental impact** of a product **variant**:

- UVC – Unitary Variable production Cost (€): direct costs (deducting overheads and taxes) related to the manufacturing of one product unit.
- GWP – Global Warming Potential (kg eq. CO_2): contribution to the global warming caused by the emission of greenhouse gases in the atmosphere.
- NRD - Natural Resources Depletion (kg antimony eq.): the depletion of non-renewable abiotic natural resources.

- Medini et al. (2011) and Bettoni et al. (2013) does not take into account the stock holding costs...

Newly added indicator…

- SHC – Stock Holding Costs (€): SHC measures the cost induced by holding one unit of the stock during a given period of time.

Variety steering during production planning
Indicators weighting

- The **high number** and **heterogeneity** of indicators are likely to impede the decision making process
- **Prioritization** provide the basis for building holistic measures, thus **facilitating the decision making process** (Medini et al., 2015)
- The weighting method adopted here is inspired by Medini et al. (2015)
- The judgment scale adopted here is the one proposed by Saaty (2008)

Assume that a predefined set of n indicators j are to be weighted:

$$P = \begin{pmatrix} \rho_{11} & \cdots & \rho_{1n} \\ \vdots & \ddots\ \rho_{ij}\ \ddots & \vdots \\ \rho_{n1} & \cdots & \rho_{nn} \end{pmatrix},\ \rho_{ij} \in\ ]0,9]$$

$$\omega_j = \frac{\sum_{k=1}^{n}\left(\frac{\rho_{ij}}{\sum_{l=1}^{n}\rho_{lj}}\right)}{n}\ ,\ j\ \in \{1..n\}$$

ω_j weight of indicator j

P pair-wise comparison matrix

ρ_{ij} the relative importance of indicator i over indicator j

Variety steering during production planning

Indicators normalization

- Normalization is based on an improved sigmoid function
- Ensures pseudo-linear mapping of the original values (values between x and x_{max}) (De Marsico et al., 2011)

$$S(x) = \frac{1 - b^{\frac{x}{x_{max}}}}{ab^{\frac{x}{x_{max}}} + 1}, \quad S(x) \in]0,1[$$

with $\mathrm{a} = 2 + \sqrt{3}$ and $\mathrm{b} = 7 - 4\sqrt{3}$.

- $nUVC$, $nSHC$, $nGWP$, and $nNRD$ are the normalized values of the indicators UVC, SHC, GWP, and NRD, respectively

$$H = \omega_{UVC}.(nUVC + nSHC) + \omega_{GWP}.nGWP + \omega_{NRD}.nNRD$$

- The lower is H ($H > 0$) the more sustainable is the product variant
- Improvement and deterioration are moderated by the indicators' weights

Variety steering during production planning

Variety optimization – objective function

- A manufacturing firm aiming to balance the production volumes among variants belonging to a given product family
- Starting from the holistic sustainability indicator defined in previous section, we obtain:

$$Z = \sum_{i \in F} \sum_{t \in T} (\omega_{UVC}.nUVC_i + \omega_{GWP}.nGWP_i + \omega_{NRD}.nNRD_i).x_{it} + \omega_{UVC}.nSHC_i.h_{it}$$

With:

i	product variant
F	product family
t	period
T	set of periods
x_{it}	decision variable representing the production volume of variant i during period t
h_{it}	decision variable representing the inventory level of variant i at the end of period t
$nUVC_i$	unitary variable cost allocated to variant i
$nGWP_i$	greenhouse gases allocated to variant i
$nNRD_i$	natural resources depletion allocated to variant i
$nSHC_i$	stock holding cost of one unit of variant i

Variety steering during production planning

Variety optimization – linear programming model

Subsequent model…

$$min \sum_{i \in F} \sum_{t \in T} (\omega_{UVC}.nUVC_i + \omega_{GWP}.nGWP_i + \omega_{NRD}.nNRD_i).x_{it} + \omega_{UVC}.nSHC_i.h_{it}$$

s.t.

$$\sum_{i \in F} x_{it} \leq C \qquad \forall t \in T$$
$$x_{it} + h_{it-1} = s_{it} + h_{it} \qquad \forall i \in F, \forall t \in T$$
$$D^-_{it} \leq s_{it} \leq D^+_{it} \qquad \forall i \in F, \forall t \in T$$
$$x_{it} \geq 0 \qquad \forall i \in F, \forall t \in T$$
$$s_{it} \geq 0 \qquad \forall i \in F, \forall t \in T$$
$$h_{it} \geq 0 \qquad \forall i \in F, \forall t \in T$$
$$\sum_{i \in F} s_{it} = S_t \qquad \forall t \in T$$

- Evaluation should also **take into account the profit** associated to each solution proposed by the model:

$$GP = \sum_{i \in F} \sum_{t \in T} s_{it}.(P_i - UVC_i) - h_{it}.SHC_i$$

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- **Illustrative example**
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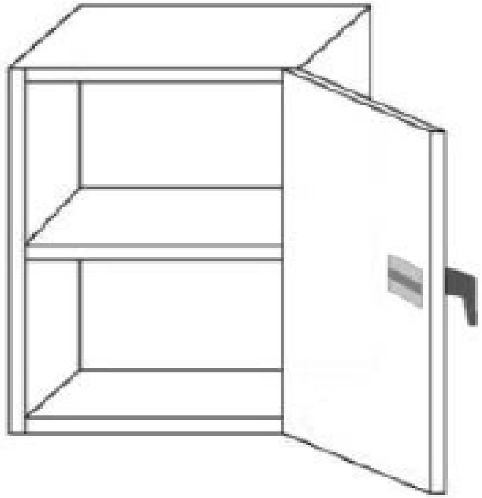
An illustrative example

Context and hypotheses

- Inspired by a real case study in the **furniture sector**
- Data about the kitchen cabinet variants is fully gathered from the case company
- **Six variants** are considered and are typically differentiated according their sizes



Source: Medini et al. (2014)

Hypotheses…

- H1: Monthly production capacity amounts to *1200* units.
- H2: Monthly storage capacity amounts to *900* units.
- H3: Initial inventory levels are *50* units from *v1, v2,v3*, *v5* and *400* from *v4, v6*
- H4: Unitary stock holding ratio is *0.3%* of the article value
- H5: Considered product family accounts for *30%* of the overall sales
- H6: Variation between upper and lower demand thresholds: *10* units

An illustrative example

Demand data

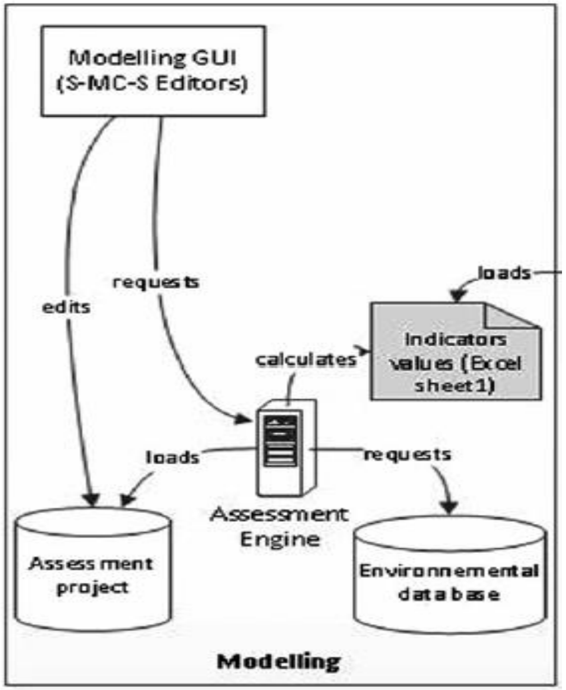
- Demand distribution over 12 months
- Estimated based on company internal reports, and H5 and H6

t	Sales (S_t)	Variants demands											
		1		2		3		4		5		6	
		D^-	D^+	D^-	D^+	D^-	D^+	D^-	D^+	D^-	D^+	D^-	D^+
1	300	10	20	10	20	10	20	115	125	10	20	115	125
2	624	10	20	10	20	10	20	277	287	10	20	277	287
3	884	39	49	39	49	39	49	349	359	39	49	349	359
4	934	42	52	42	52	42	52	368	378	42	52	368	378
5	982	44	54	44	54	44	54	388	398	44	54	388	398
6	1260	58	68	58	68	58	68	499	509	58	68	499	509
7	1360	63	73	63	73	63	73	539	549	63	73	539	549
8	1374	64	74	64	74	64	74	544	554	64	74	544	554
9	1260	58	68	58	68	58	68	499	509	58	68	499	509
10	1422	66	76	66	76	66	76	564	574	66	76	564	574
11	1356	63	73	63	73	63	73	537	547	63	73	537	547
12	1248	57	67	57	67	57	67	495	505	57	67	495	505

An illustrative example

Indicators values calculation

S-MC-S Editors (**FP7 - Sustainable mass customization – Mass Customization for Sustainability**)



Source: Medini et al. (2015)

→ Modelling of the kitchen cabinet product family, manufacturing and logistics processes, and supply chain actors

Variant	UVC	GWP	NRD	$Price$
1	11.21	20.95	0.19	350
2	13.41	23.56	0.22	350
3	14.35	22.84	0.21	350
4	13.80	22.36	0.21	350
5	16.10	23.07	0.22	350
6	14.86	22.10	0.21	350

Unitary values of the indicators

An illustrative example

Indicators normalization and weighting

- Afterwards, apply the sigmoid function to the indicators values
- Weigh the indicators

→ Firm's concerns are dominated by the economic perspective

Variant	UVC	GWP	NRD
1	0.77	0.94	0.19
2	0.83	0.96	0.22
3	0.85	0.95	0.21
4	0.84	0.95	0.21
5	0.88	0.95	0.22
6	0.86	0.95	0.21

Normalized indicators' values

Indicator	weight
UVC	0.53
GWP	0.07
NRD	0.40

Weights

↓ ↓

Variety optimization

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An illustrative example

Optimization output (1/2)

Afterwards…

- Implementation using LINGO 15.0.20 software
- Intel ™ Core ™ with 2.40 GHz processor.
- The model includes 216 variables and 469 constraints.

Output…

Indicators' values

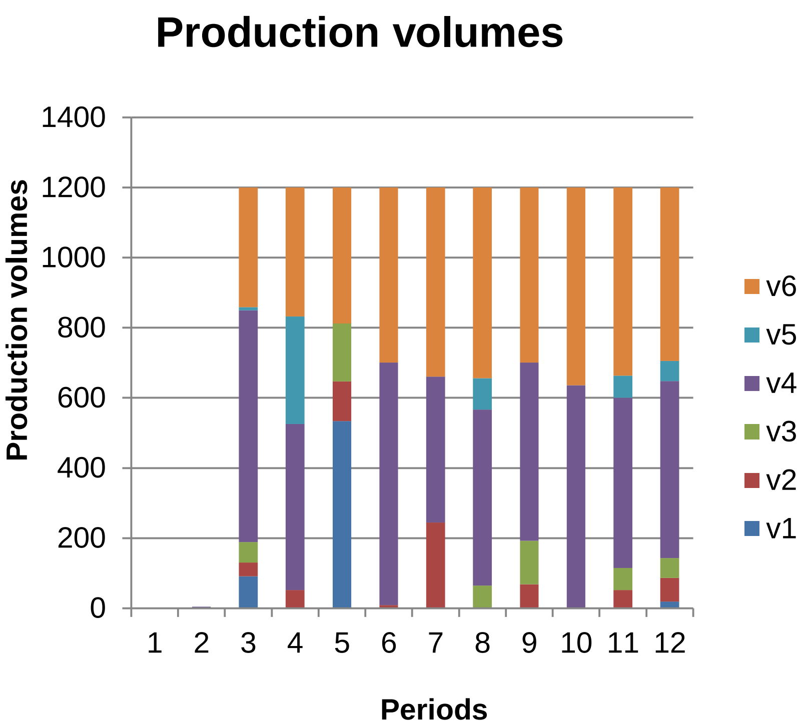
Indicator	Value
UVC (€)	175 924
GHG (kg eq. CO2)	267 660
NRD (kg antimony eq.)	2 520
GP (€)	4 375 476

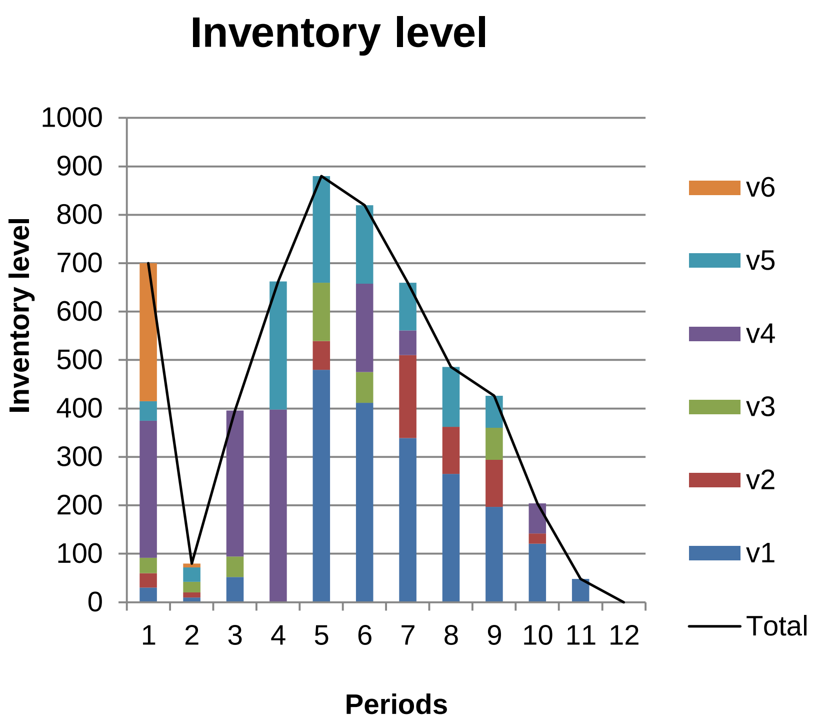
Sales planning

t	s_{1t}	s_{2t}	s_{3t}	s_{4t}	s_{5t}	s_{6t}
1	20	20	18	117	18	115
2	20	20	10	287	10	277
3	49	49	39	359	39	349
4	52	52	42	378	42	368
5	54	54	44	398	44	388
6	68	68	58	509	58	499
7	73	73	63	549	63	539
8	74	74	64	554	64	544
9	68	68	58	509	58	499
10	76	76	66	574	66	564
11	73	73	63	547	63	537
12	67	67	57	505	57	495

An illustrative example

Optimization output (2/2)





- Only minor production volumes are launched during first periods (i.e. 4 units) because of the initial inventory levels (cf. H3).
- Inventory level culminates at the fifth month because of the higher average demands occurring during periods 6 to 12

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Conclusion

Insights from the case study

- An approach relying on weighting, normalization and optimization in order to **support the decision making** on variety levels from a **production planning perspective**
  - ➢ Balancing sales among variants to reduce the overall sustainability impact of the product family
  - ➢ Balancing the production volumes and resulting inventory levels among the computation periods to minimize total costs

→ Combination of indicators weights and values allocated to product variants **towards the identification of the tradeoffs**

→ Decision making support regarding **product mix**

→ Potential of the approach to **steer variety towards an overall objective of sustainable performance**

Conclusion

Research perspectives

Extension opportunities to the PSS domain…

- Increasing PSS offering variety is an important lever to meet diversified customers' demands in both B2C and B2B contexts (Aurich, et al., 2010; Geum et al., 2012; Nishino et al., 2014)
- Sustainability concerns are a prominent feature for many companies adopting the PSS (Beuren et al., 2013)

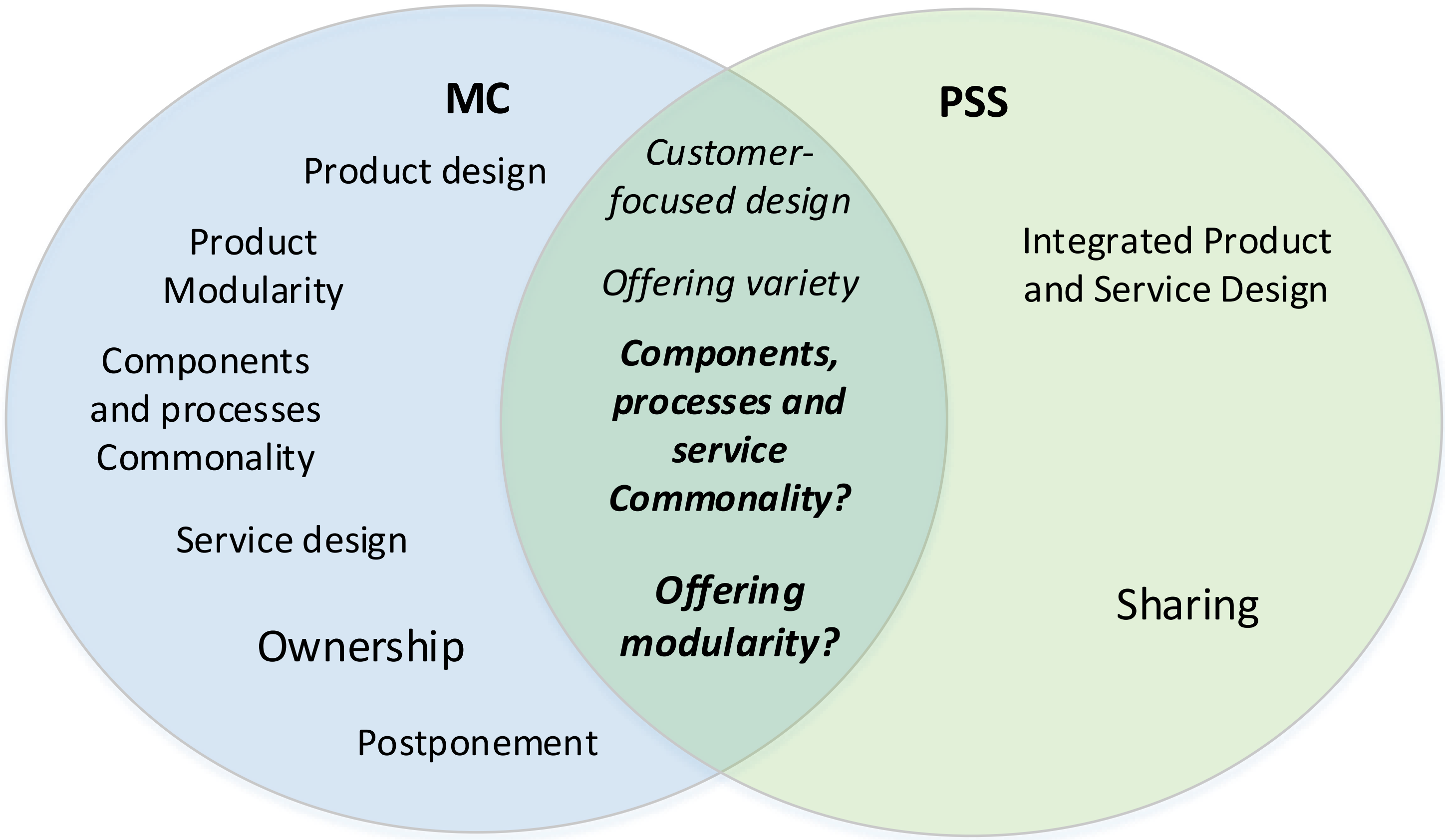
But several key issues need to be analyzed thoroughly…

- The model should support **the solution space** comprised of **products and services**
- The production system/supply chain delivering the PSS combines both **manufacturing and service processes**
- The performance of service delivery requires **other indicators** (e.g. customer satisfaction)

Conclusion

Research perspectives

Synergies between mass customization and PSS…



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Thank you!