Sustainable Multi-objective Process Plan Generation in Reconfigurable Manufacturing Environment: Evolutionary-based Approaches

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Outline

Context and Motivations (1)

Evaluation Of Industry

Industry 1.0

Mechanization, steam Power, Weaving Loom

Mechanisation

1784

Industry 2.0

Mass Production, assembly line, electrical energy

Electrification

1870

Industry 3.0

Automation, computers and electronics

Automation

1969

Industry 4.0

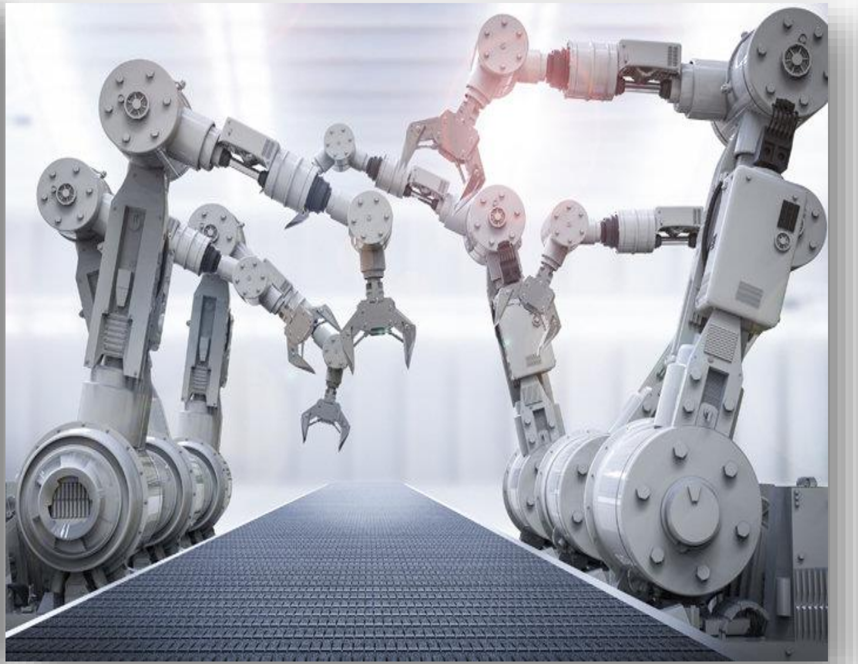
Cyber Physical System, Internet of Things, network

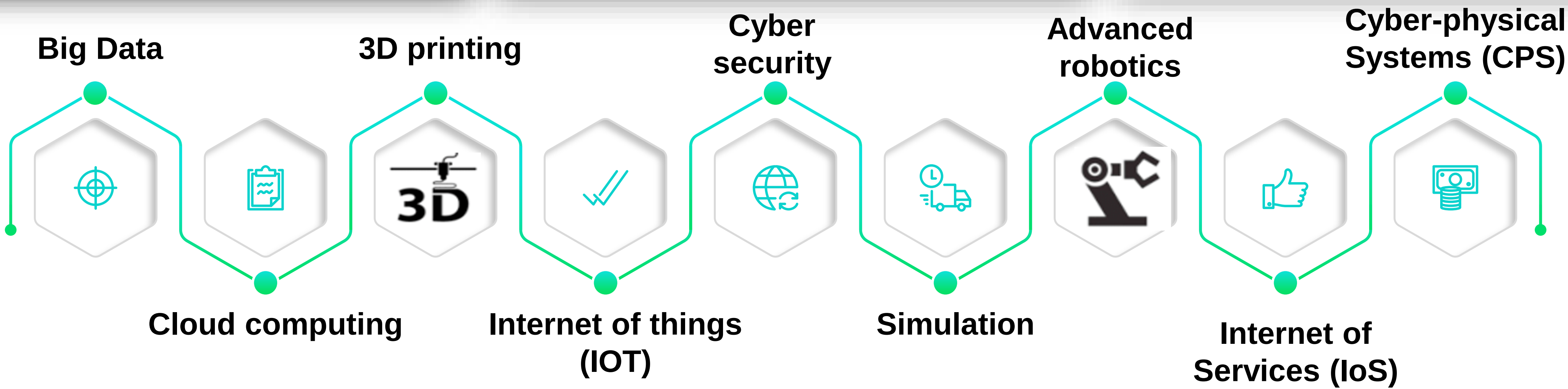
Digitisation

TODAY

Context and Motivations (2)

Industry 4.0





Context and Motivations (3)
Evaluation Of Manufacturing Paradigms

DMS
Dedicated Manufacturing System

FMS
Flexible Manufacturing System

RMS
Reconfigurable Manufacturing System

Sustainable Manufacturing

1913 — ***Mass Production***

1980 — ***Mass Customization***

2000 — ***Mass Individualization***

2010 — ***Sustainability***

Reconfigurable Manufacturing System (RMS) (1)

(DMS : Dedicated Manufacturing Systems)

- **DMSs, also known as transfer lines or production lines, are designed to manufacture a single type of product with a very high production volume.**
- **A DMS is based on a collection of relatively simple machines, arranged sequentially along a line where the raw material moves from one machine to another in a synchronized manner.**
- **A DMS is economically viable when very large quantities of the product need to be manufactured.**

Reconfigurable Manufacturing System (RMS) (2)

FMS : Flexible Manufacturing Systems

- A FMS is an integrated group of machining units, generally CNC (Computer Numerically Controlled) machine tools, connected by an automated material handling system, whose operation is controlled by a supervisory computer.
- A FMS allows for the redefinition of products to meet new market demands without requiring significant investments in the initial manufacturing system.
- Unlike DMSs (high volume/low variety), FMSs ensure "mass customization" (i.e., producing a variety of components and products using the initial capacity).

Reconfigurable Manufacturing System (RMS) (3)

RMS : Reconfigurable Manufacturing System

An RMS is a production system in which machines, machine components, and material handling systems can be added, removed, modified, or replaced as needed to meet the changing demands of the economic context (Koren et al., 1999).

Reconfigurable Manufacturing System (RMS) (4)

Dedicated

Reconfigurable

Flexible

Reconfigurable Manufacturing System (RMS) (5)

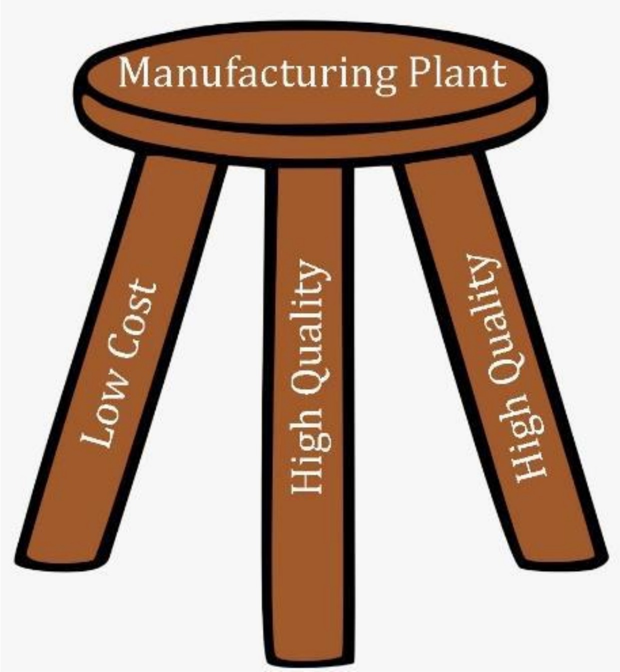
Important

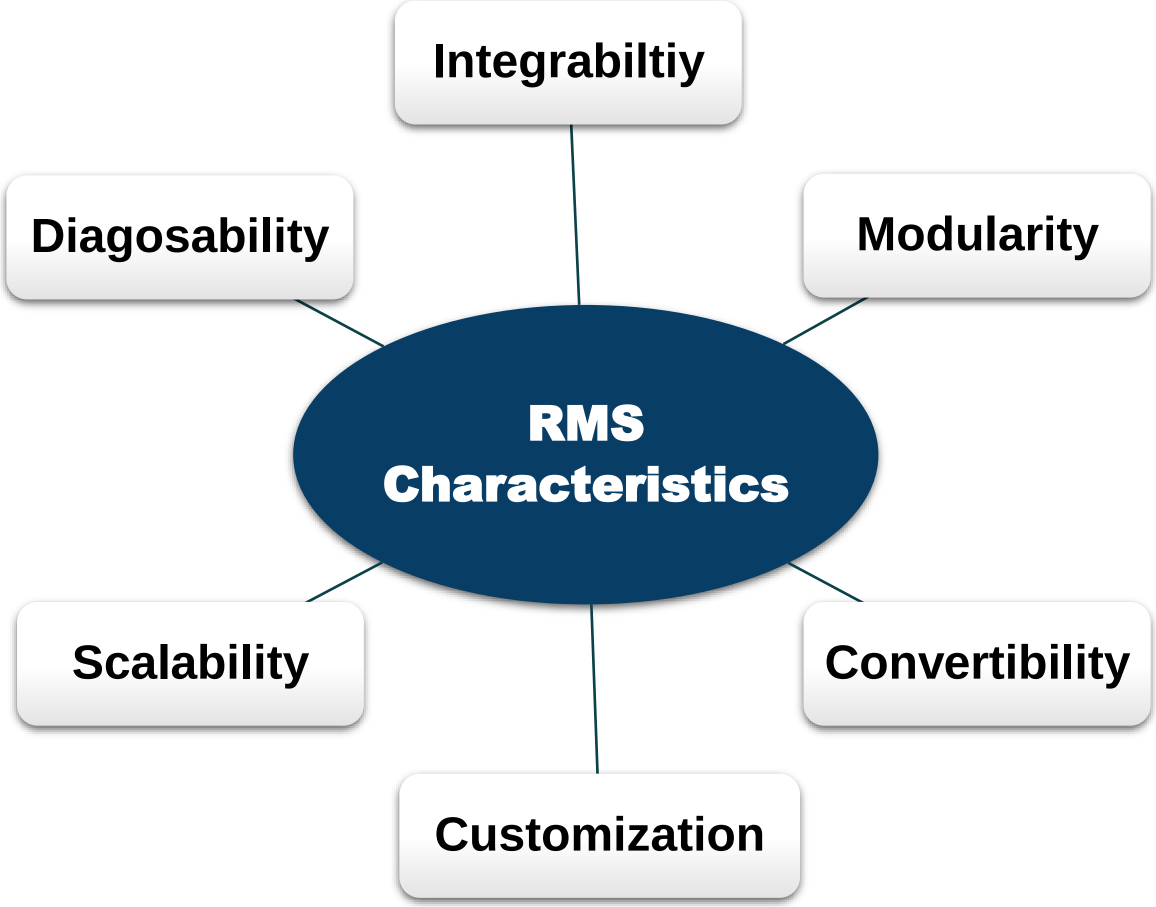
According to Koren (2006), RMSs are not only expected to combine the high throughput of DMSs with the flexibility of FMSs, but also to provide a high degree of responsiveness to changing production requirements achieved through:

1. **The design of systems and machines with adjustable structures, enabling modifications and scalability at both the system and machine levels.**
2. **A system architecture offering customizable flexibility, sufficient to produce a targeted range of products, typically within the same product family.**

Reconfigurable Manufacturing System (RMS) (6)

RMS Characteristics

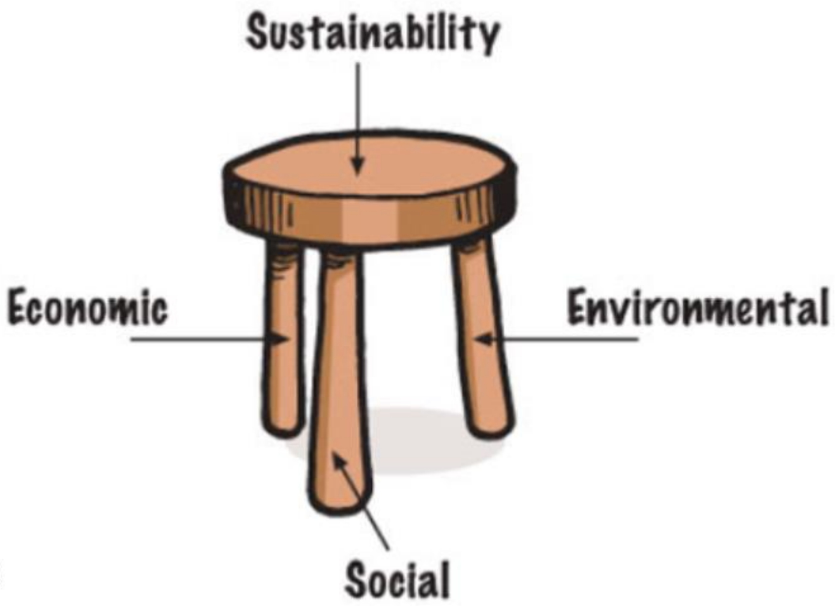


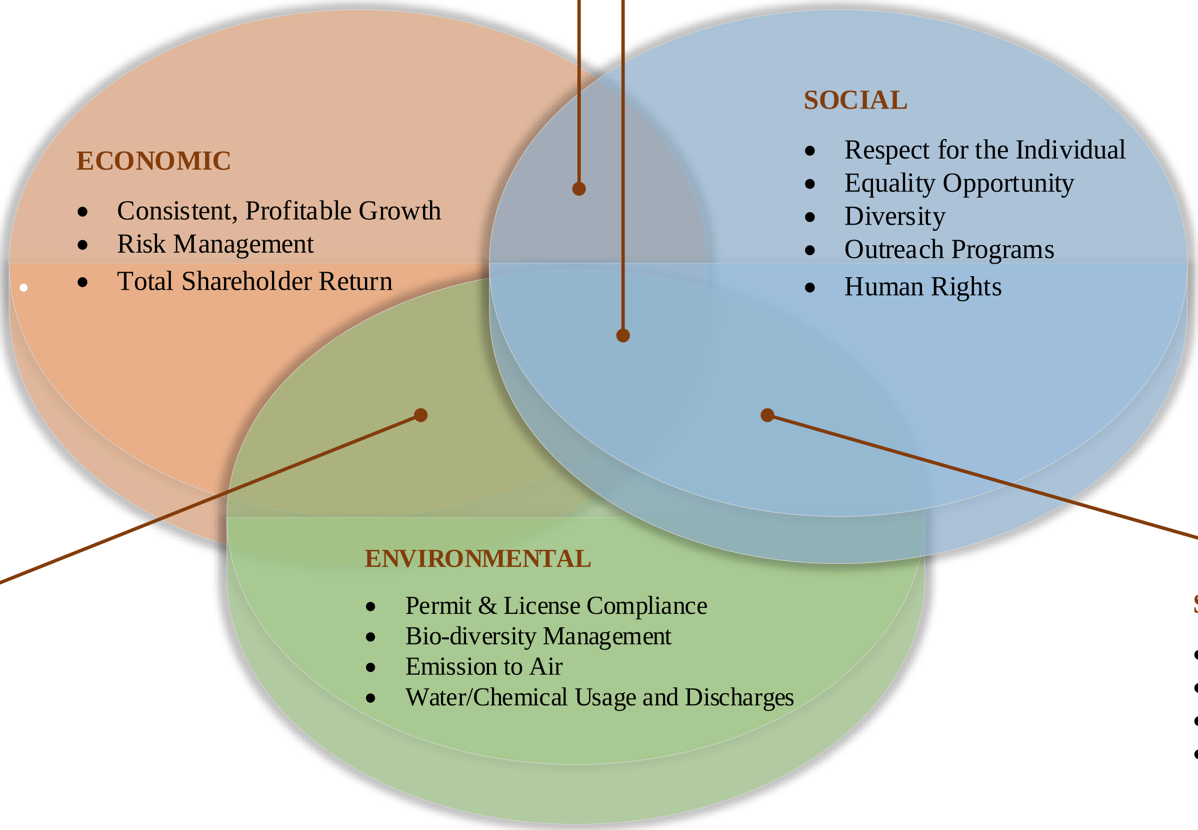


RMS characteristics (Koren *et al.*, 1999)

Sustainability and Sustainable Manufacturing (1)

Sustainability





SOCIO-ECONOMIC

- Employment
- Training & Development
- Local Economies & Enterprise
- Social & Community
- Spocerships

SUSTAINABILITY

An integrated approach to Environmental, Social & Economic impact issues (both internal and external) leads to long term, sustainable profit growth

ECONOMIC

- Consistent, Profitable Growth
- Risk Management
- Total Shareholder Return

SOCIAL

- Respect for the Individual
- Equality Opportunity
- Diversity
- Outreach Programs
- Human Rights

ENVIRONMENTAL

- Permit & License Compliance
- Bio-diversity Management
- Emission to Air
- Water/Chemical Usage and Discharges

ECO-ECONOMY

- Resource Efficiency
- Energy Efficiency
- Global Energy Issues

SOCIO-ENVIRONMENTAL

- Health & Safety
- Legalization & Regulation
- Climate Change
- Crisis Management

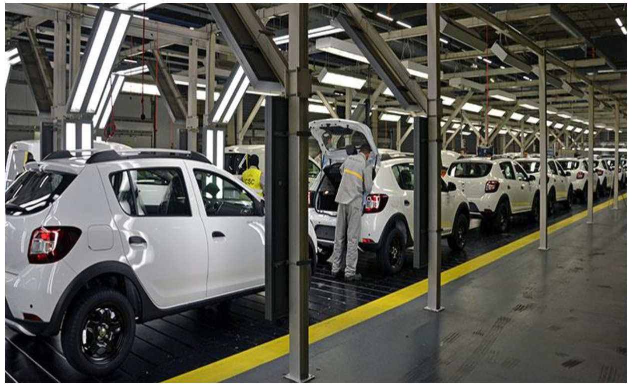
The three pillars of sustainability (ENV, 2010)

Sustainability and Sustainable Manufacturing (2)

Sustainable Manufacturing



Systems / Machines



Our main motivation

RMS

Sustainable Manufacturing

Sustainable Multi-Objective Process Plan Generation in a Reconfigurable Manufacturing Environment

State of the art (1)
RMS vs Sustainability

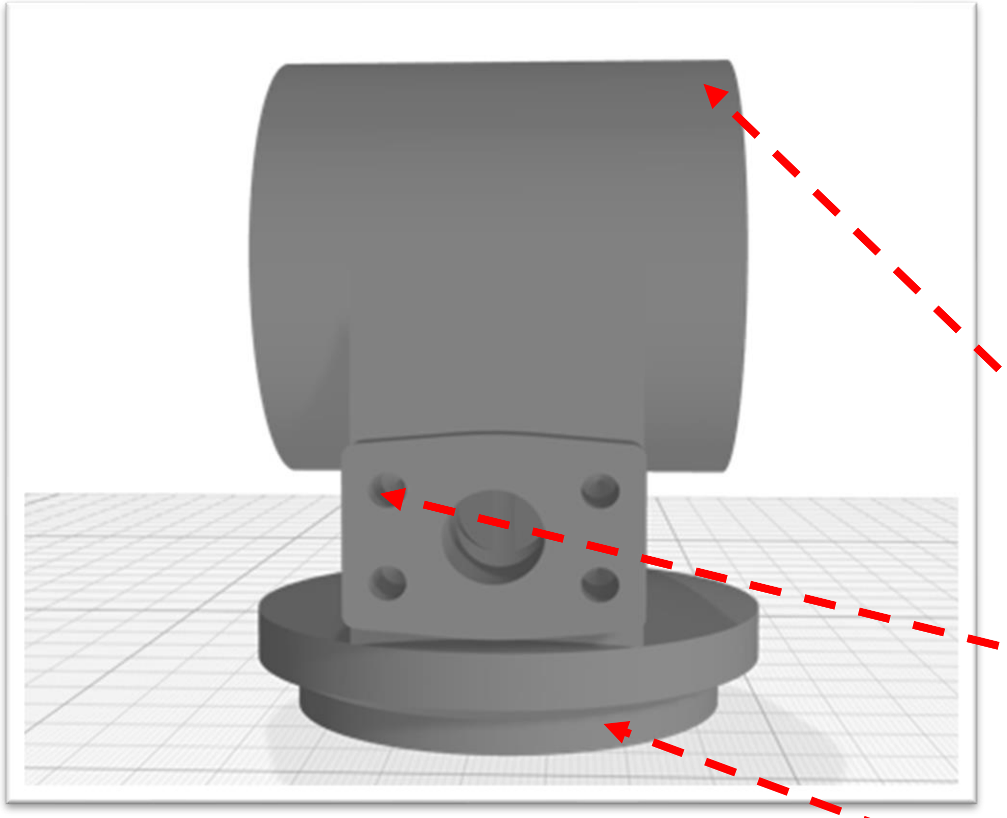
Problems	Authors	Approches
System design	Battaïa et al. (2017), Renna (2017), Andersen et al. (2017), Koren et al. (2010, 2016), Delorme et al. (2016), Bensmaine et al. (2014), Guan et al. (2012), Lokesh & Jain (2010), Deif & ELMaraghy (2006)	MILP, Heuristic, Metaheuristic, AMOSA, NSGA-II, Simulation
Process planning	Xia et al. (2018), Eguia and al. (2017), Hees & Reinhart (2015), Niroomand et al. (2014), Mohapatra et al. (2014), Bensmaine et al. (2013), Chaube et al. (2012), ELMaraghy (2007)	MILP, Heuristic, Metaheuristic, AMOSA, NSGA-II
Performance indicators	Lamech et al. (2017), Goyal & Jain (2016), Dahane & Benyoucef (2016), Gupta et al. (2015), Mittal et al. (2014)	Heuristic, Metaheuristic (AMOSA, NSGA-II), TOPSIS, DSM
RMT design	Dou et al. (2016), Gadalla & Deyi (2016), Maniraj et al. (2015), Hasan et al. (2013), Goyal et al. (2013), Padayachee et al. (2009), Moon (2000)	Heuristic, Metaheuristic, MOMIP, ACO, NSGA-II, PSO,
Sustainability	Khezri and al. (2021), Touzout and Benyoucef (2018), Ghanei and AlGeddawy (2016), Zhang and al. (2015)	MILP, Heuristic, Metaheuristic, SPEA-II, NSGA-II

State of the art (2)

RMS and Sustainability

References	Cost		Time	Process Planning	Sustainability			Approaches
	Production	Sustainability			GHG	Energy	Wastes	
Choi and Xirouchakis (2015)				✓		✓		LP
Mohapatra and al. (2015)	✓		✓	✓				NSGA-II
Afrin and al. (2016)	✓				✓			BSSPMO
Aljuneidi and Bulgak (2016)	✓						✓	MILP
Haddou-Benderbal and al.(2016)	✓		✓	✓				NSGA-II
Manupati and al. (2016)			✓	✓				NSGA-II, MNSGA-II, MBBGA
Haddou-Benderbal and al. (2017)			✓	✓				NSGA-II
Haddou-Benderbal and al. (2018)	✓		✓	✓				AMOSA, TOPSIS
Touzout and Benyoucef (2019b)	✓		✓	✓				NSGA-II, I-MOILP
Kumar and al. (2019)	✓		✓	✓				MOSOMA
Khezri and al. (2019)	✓	✓	✓	✓		✓		AUGECON
Bortolini and al. (2019)	✓		✓					LP-Solver Optimizer
Khezri and al. (2020)	✓	✓	✓	✓	✓	✓	✓	WGP
Massimi and al. (2020)				✓		✓		Heuristic-based NL-MIP
Yazdani and al. (2021)	✓	✓	✓	✓	✓	✓	✓	LR
This work	✓	✓	✓	✓	✓	✓	✓	WGA, RWGA, SPEA-II, NSGA-II, DNSGA- II, R-NSGA-II, PBI-R-NSGA-II, SC-D-NSGA-II, NSGA-III,SE-NSGA6III, SC-NSGA-III.

Problem Description (1)

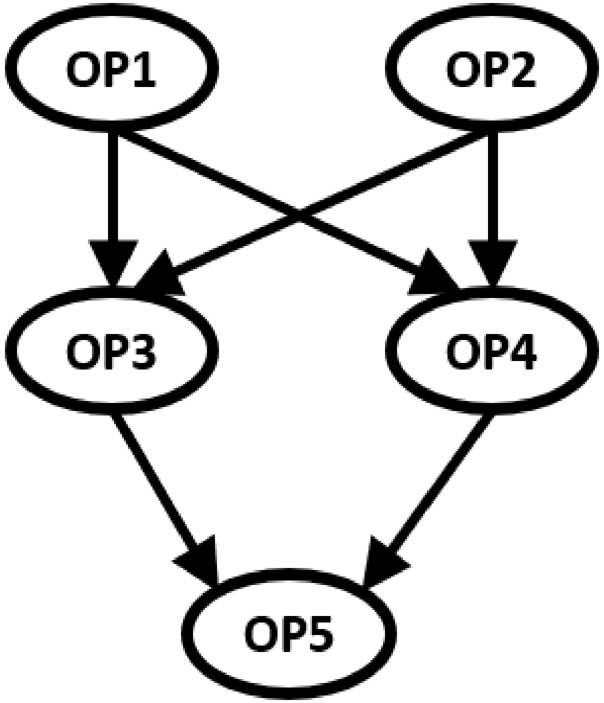


Characteristic 3
requires 1 operations

Characteristic 2
requires 2 operations

Characteristic 1
requires 2 operations

Example of a part to be manufactured



A simple operations precedence graph

Problem Description (2)

- ✓ Precedence constraints
- ✓ Tool Approach Directions
- ✓ Tools

Operation

- ✓ Configurations
- ✓ Tool Approach Directions
- ✓ Tools

Machine

OP	TAD						Tools
	+X	+Y	+Z	-X	-Y	-Z	
Op_1		×	×	×	×		T1
Op_2		×	×				T1
Op_3	×	×		×			T3
Op_4	×	×	×	×			T1
Op_5						×	T2

Operations TADs and Tools requirements

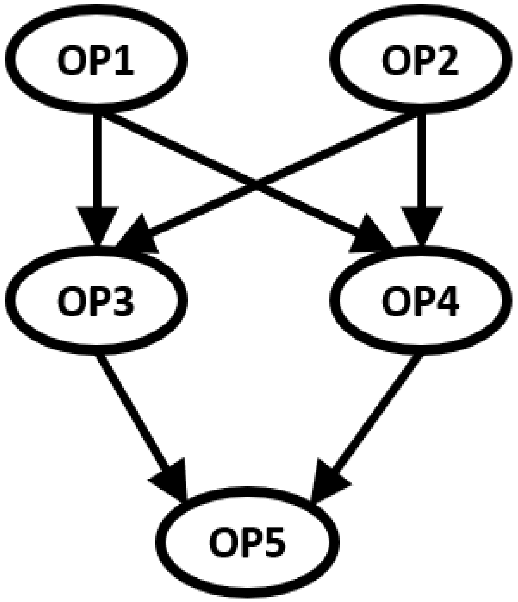
Ms	Cs	TAD						Tools
		+X	+Y	+Z	-X	-Y	-Z	
M_1	C_1			×		×		T1,T2
	C_2						×	
	C_3		×	×		×	×	
	C_4	×			×			
M_2	C_1					×		T1, T2
	C_2		×	×	×	×		
M_3	C_1	×	×	×	×			T1, T3

Machines disposal TADs and Tools

Problem Description (3)

Process plan generation

- ✓ Associating the operations and triplets (machine, configuration and tool).
- ✓ Respect the precedence constraint.
- ✓ Respect the Sustainable criteria's, Cost and Time



	Operation	OP2	OP1	OP4	OP3	OP5
Triplet	**Machine**	M1	M2	M3	M3	M1
	Configuration	C3	C2	C1	C1	C2
	Tool	T1	T1	T3	T1	T2

An illustrative structure of a process plan

Mathematical Formulation (1)

Four objectives are minimized

1. **The total production cost.**
2. **The total production time.**
3. **The hazardous liquid wastes.**
4. **The amount of the greenhouse gases emitted from energy consumption.**

Mathematical Formulation (2)

Minimization of the total production cost f_C

$\boldsymbol{Min\ f_C}$ = Processing cost + Changing machine cost + Changing configuration and tool cost

Processing Cost = $\sum_{p=1}^{n}\sum_{i=1}^{n}\sum_{t\in TO_i} x_{i,p}^{t} \times Pc_{i,t} \times Pt_{i,t}$

Changing machine Cost = $\sum_{p=2}^{n}\sum_{j=1}^{m}\sum_{j'=1}^{m} MC_p^{p-1}(j,j') \times CCM_{j,j'} \times TCM_{j,j'}$

Changing configuration and tool Cost = $\sum_{p=2}^{n}\sum_{j=1}^{m}\sum_{t\in Mj}\sum_{t'\in Mj'} TC_p^{j,p-1}(t,t') \times \left(CCT_{tl,tl'} \times TCT_{tl,tl'} + CCC_{c,c'} \times TCC_{c,c'}\right)$

Mathematical Formulation (3)

Minimization of the total production time f_t

$\boldsymbol{Min\ f_t}$ = Processing time + Changing machine time + Changing configuration and tool time

$$\text{Processing Time} = \sum_{p=1}^{n}\sum_{i=1}^{n}\sum_{t\in TO_i} x_{i,p}^{t} \times Pt_{i,t}$$

$$\text{Changing machine Time} = \sum_{p=2}^{n}\sum_{j=1}^{m}\sum_{j'=1}^{m} MC_p^{p-1}(j,j') \times TCM_{j,j'}$$

Mathematical Formulation (4)

Minimization of Liquid Hazardous Waste f_{LHW}

$\boldsymbol{Min\ f_{LHW}}$ =Liquid Hazardous Waste

$$f_{LHW} = \sum_{p=1}^{n} \sum_{i=1}^{n} \sum_{t \in TO_i} x_{i,p}^{t} \times l_{i,m} \times Pt_{i,t} \times EP_{i,t}$$

Where:

$l_{i,m}$: Liquid Consumption
$EP_{i,t}$: Liquid Waste Percentage
$Pt_{i,t}$: Total processing Time

Mathematical Formulation (5)

Minimization of Green House Gases f_{GHG}

$$f_{GHG} = f_{fef} \times \text{Total energy consumption} + \sum_{p=1}^{n} \sum_{i=1}^{n} \sum_{t \in TO_i} \sum_{g \in G} x_{i,p}^{t} \times Pt_{i,t} \times f_{i,g} \times GWP_g$$

Start up energy consumption = $\sum_{p=1}^{n} \sum_{i=1}^{n} \sum_{j=1}^{m} \sum_{t \in TO_i} y_{p,t}^{j} \times x_{i,p}^{t} \times IEC_j$

Linearized Method

$$\boldsymbol{y_{p,t}^{j} \times x_{i,p}^{t} \equiv z}$$

$$\boldsymbol{S.t.}$$

$$\boldsymbol{z \leq x_{i,p}^{t}}$$

$$\boldsymbol{z \leq y_{p,t}^{j}}$$

$$\boldsymbol{z \geq y_{p,t}^{j} + x_{i,p}^{t} - 1}$$

$$\boldsymbol{z \in \{0, 1\}}$$

Processing Energy consumption = $\sum_{p=1}^{n} \sum_{i=1}^{n} \sum_{t \in TO_i} x_{i,p}^{t} \times Pt_{i,t} \times Pe_{i,t}$

Changing machine Energy consumption = $\sum_{p=2}^{n} \sum_{j=1}^{m} \sum_{j'=1}^{m} MC_p^{p-1}(j, j') \times ECM_{j\,j'} \times TCM_{j,j'}$

Changing configuration and tool Energy consumption

$$= \sum_{p=2}^{n} \sum_{j=1}^{m} \sum_{t \in M_j} \sum_{t' \in Mj} TC_p^{j,p-1}(t, t') \times \left(\left(TTC_{tl,tl'} \times ETC_{tl,tl'} + TCC_{c,c'} \times ECC_{c,c'} \right) \right)$$

Mathematical Formulation (6)

Multi-Objective Integer Non Linear Programming Model

Four objectives are minimized

Minimization of the total production cost f_C

$$Min\ f_C$$

Minimization of the total production time f_t

$$Min\ f_t$$

Minimization of Liquid Hazardous Waste f_{LHW}

$$Min\ f_{LHW}$$

Minimization of Green House Gases f_{GHG}

$$Min\ f_{GHG}$$

Subject to

$$\sum_{i=1}^{n} \sum_{t \in TO_i} x_{i,p}^t = 1 \qquad \forall\ p = 1 \dots n$$

$$\sum_{p=1}^{n} \sum_{t \in TO_i} x_{i,p}^t = 1 \qquad \forall\ i = 1 \dots n$$

$$\sum_{t \in TO_i} x_{i,p}^t \times |PR_i| \leq \sum_{p'=1}^{p-1} \sum_{t' \in TO_{i'}} x_{i',p'}^{t'} \qquad \forall\ i = 1 \dots n, \forall\ p = 2 \dots n$$

$$\sum_{j=1}^{m} \sum_{t \in TM_j} y_{p,t}^j = 1 \qquad \forall\ p = 1 \dots n$$

$$y_{p,t}^j \geq x_{i,p}^t \qquad \forall\ i = 1 \dots n, \forall\ p = 1 \dots n, \ \forall\ j = 1 \dots m, \forall\ t \in TM_j$$

$$\sum_{i=1}^{n} x_{i,p}^t + \sum_{i=1}^{n} x_{i,p-1}^{t'} \leq MC_p^{p-1}(j, j') + 1 \qquad \forall\ p = 2 \dots n, \forall\ t, t' \in T$$

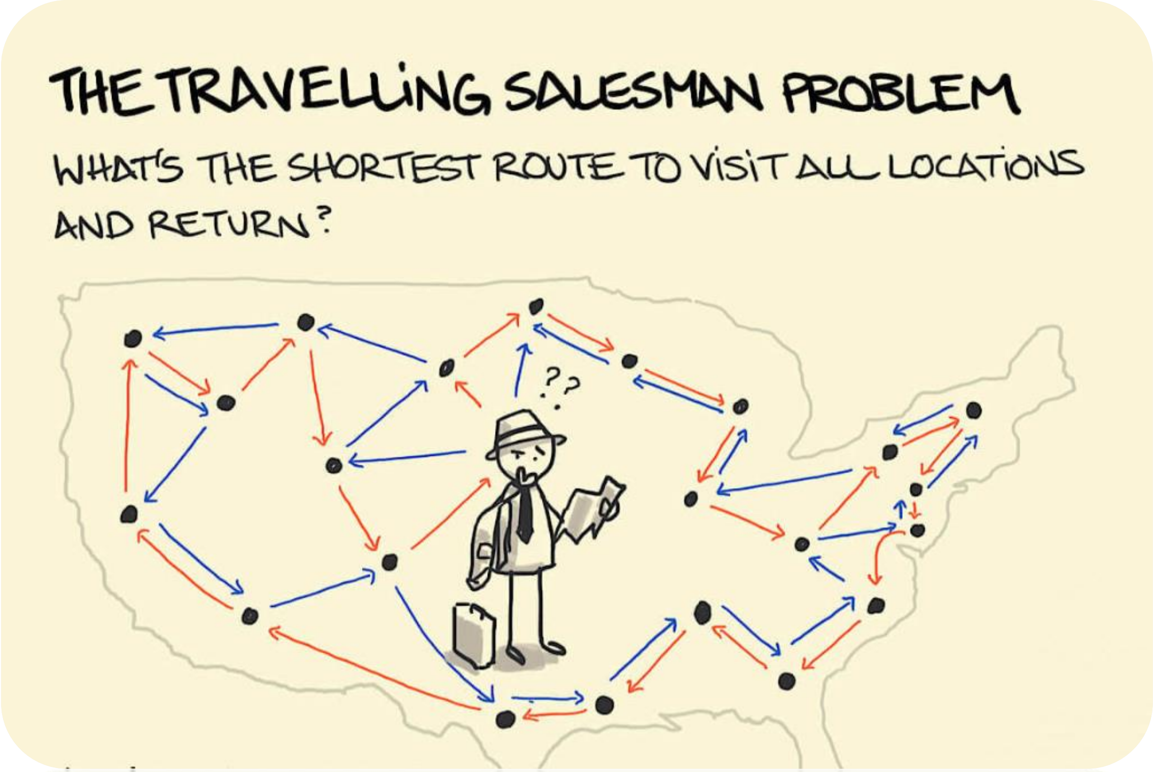
$$y_{p,t}^j + y_{p-1,t'}^j \leq TC_p^{j,p-1}(t, t') + 1 \qquad \forall\ p = 2 \dots n, \forall\ j = 1 \dots m, \ \forall\ t, t' \in TM_j$$

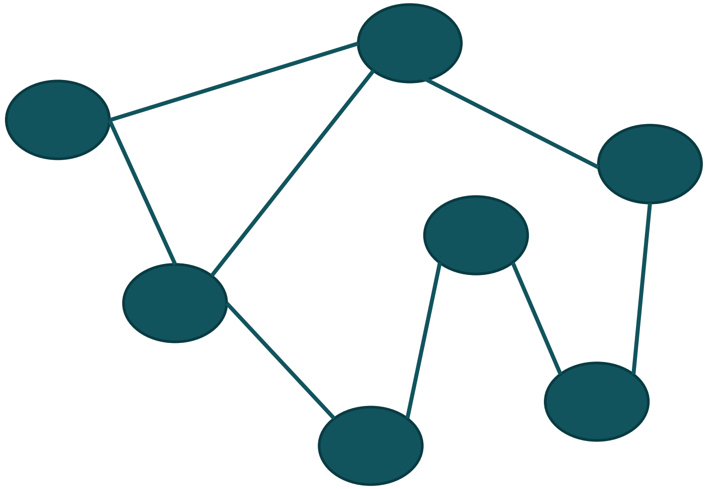
$$\sum_{t,t' \in TM_j} TC_p^{j,p-1}(t, t') = 1 \qquad \forall\ p = 1 \dots n, \forall\ j = 1 \dots m$$

$$\sum_{p=1}^{n} \sum_{i=1}^{n} \sum_{t \in TO_i} x_{i,p}^t \times l_{i,t} \times Pt_{i,t} \leq L$$

WHY DIFFERENT APPROACHES ?

RMS is a **complex system** and associated problems are classified as **NP−HARD**





Travelling Salesman Problem (TSP)

Process Plan Representation

	Operation	OP2	OP1	OP4	OP3	OP5
Triplet	**Machine**	M1	M2	M3	M3	M1
	Configuration	C3	C2	C1	C1	C2
	Tool	T1	T1	T3	T1	T2

Process Plan Representation

Operation	0.76	0.81	0.07	0.49	0.37
Triplet	0.23	0.34	0.72	0.15	0.51

Encoded process plan

Algorithm Process Plan Decoding Procedure

input data $M = (a_{i,j})$: matrix of the coded process plan
p: process plan
for $i = 1 : n$ do
    get noPred: the list of operations with no unperformed predecessors
    indexOperation=$\lceil a_{1,i} \times$ size(noPred)$\rceil$
    $p_i^{operation}$ = noPred(indexOperation)
    indexTriplet =$\lceil a_{2,i} \times \text{size}(T_{p_i^{\text{operation}}}) \rceil$
    $p_i^{triplet} = T_{p_i^{\text{operation}}}(indexTriplet)$
    for $j \in successors(p_i^{operation})$ do
        delete $p_i^{operation}$ from predecessors(j)
    end for
end for

Genetic Algorithm Operators

Parent 1	0.21	0.89	0.17	0.52	0.34
	0.36	0.09	0.91	0.53	0.44
Parent 2	0.09	0.65	0.39	0.17	0.95
	0.97	0.34	0.12	0.48	0.59
Child 1	0.21	0.89	0.17	0.17	0.95
	0.36	0.09	0.91	0.48	0.59
Child 2	0.09	0.65	0.39	0.52	0.34
	0.97	0.34	0.12	0.53	0.44

Crossover operations

Parent 3	0.19	0.85	0.11	0.24	0.88
	0. 77	0.32	0.49	0.04	0.95
Child 3	0.88	0.85	0.11	0.24	0.19
	0. 95	0.32	0.49	0.04	0.77

Mutation operations

Parent 4	0.89	0.56	0.01	0.37	0.83
	0. 41	0.52	0.93	0.60	0.12
Child 4	0.02	0.23	0.96	0.05	0.17
	0. 11	0.07	0.14	0.59	0.43

Perturbation operations

Proposed Approaches (1)

Approaches

Strength Pareto Evolutionary Algorithm (SPEA-II)

Weighted Genetic Algorithms (WGA)

Random Weighted Genetic Algorithm (RWGA)

Versions of Non-Dominated Sorting Genetic Algorithm II (NSGA-II)

- ❑ Dynamic Non-Dominated Sorting Genetic Algorithm II **(D-NSGA-II)**
- ❑ Reference Non-Dominated Sorting Genetic Algorithm II **(R-NSGA-II)**
- ❑ Penality Reference Point Non-Dominated Sorting Genetic Algorithm II **(PBI-R-NSGA-II)**
- ❑ Similarity Coefficient Dynamic Non-Dominated Sorting Genetic Algorithm II **(SC-D-NSGA-II)**

Versions of Non-Dominated Sorting Genetic Algorithm III (NSGA-III)

- ❑ Selection & Elimination Non-Dominated Sorting Genetic Algorithm III **(SE-NSGA-III)**
- ❑ Similarity Coefficient Non-Dominated Sorting Genetic Algorithm III **(SC-NSGA-III)**

Proposed Approaches (2)
The similarity coefficient computation

Chromosome a	0.35	0.88	0.98	0.02	0.67
	0.86	0. 55	0.14	0.79	0.23
Chromosome b	0.11	0.82	0.51	0.29	0. 93
	0.61	0.54	0.47	0.43	0.62

Xa	0.35	0.88	0.98	0.02	0.67	0.86	0.55	0.14	0.79	0.23
Xb	0.11	0.82	0.51	0.29	0.93	0.61	0.54	0.47	0.43	0.62

3	8	9	0	6	8	5	1	7	2
1	8	5	2	9	6	5	4	4	6

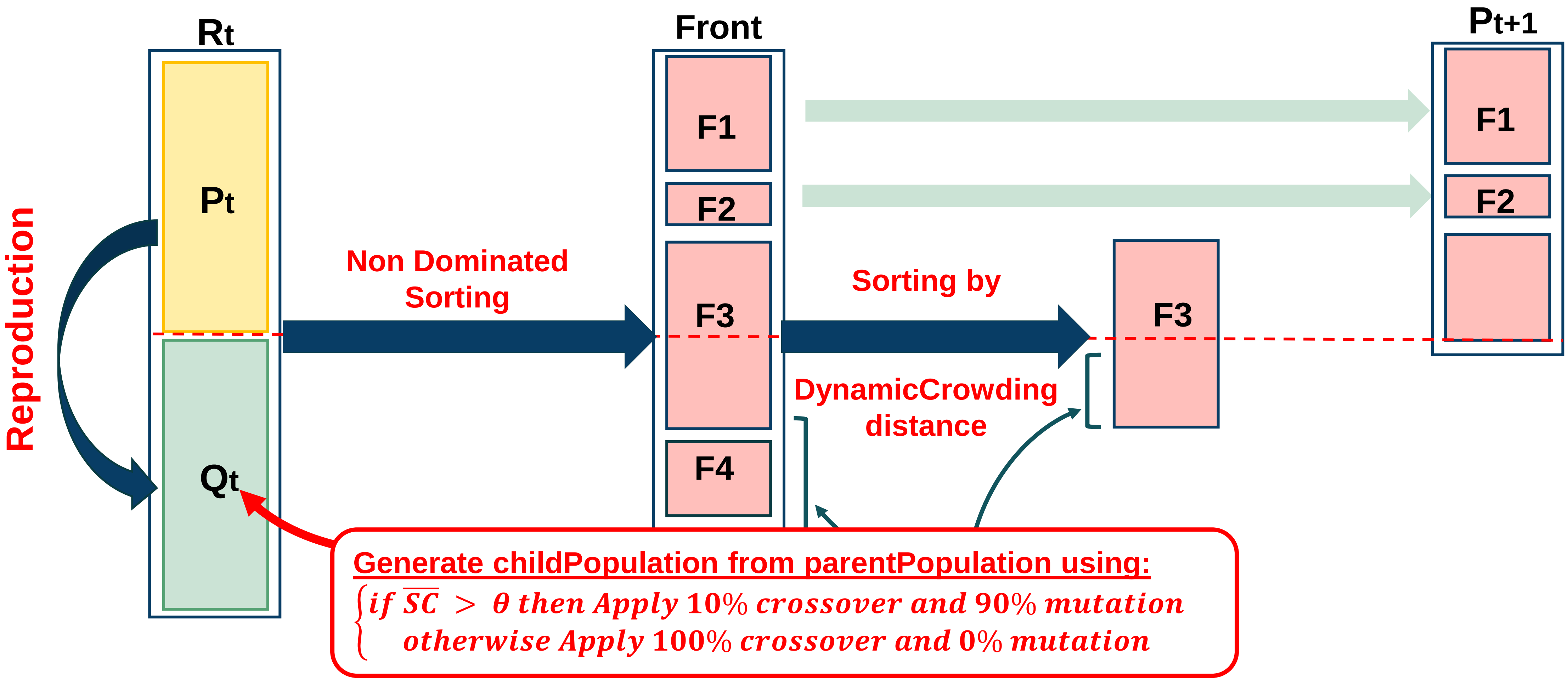
$$SC_{ab} = \frac{0+1+0+0+0+0+1+0+0+0}{5*2} = \frac{2}{10}$$

The ASC $\overline{SC}$ of the population is calculated as follows:

$$\overline{SC} = \frac{\sum_{a=1}^{N_{POP}-1}\sum_{b=a+1}^{N_{POP}} SC_{ab}}{\binom{N_{POP}}{2}}$$

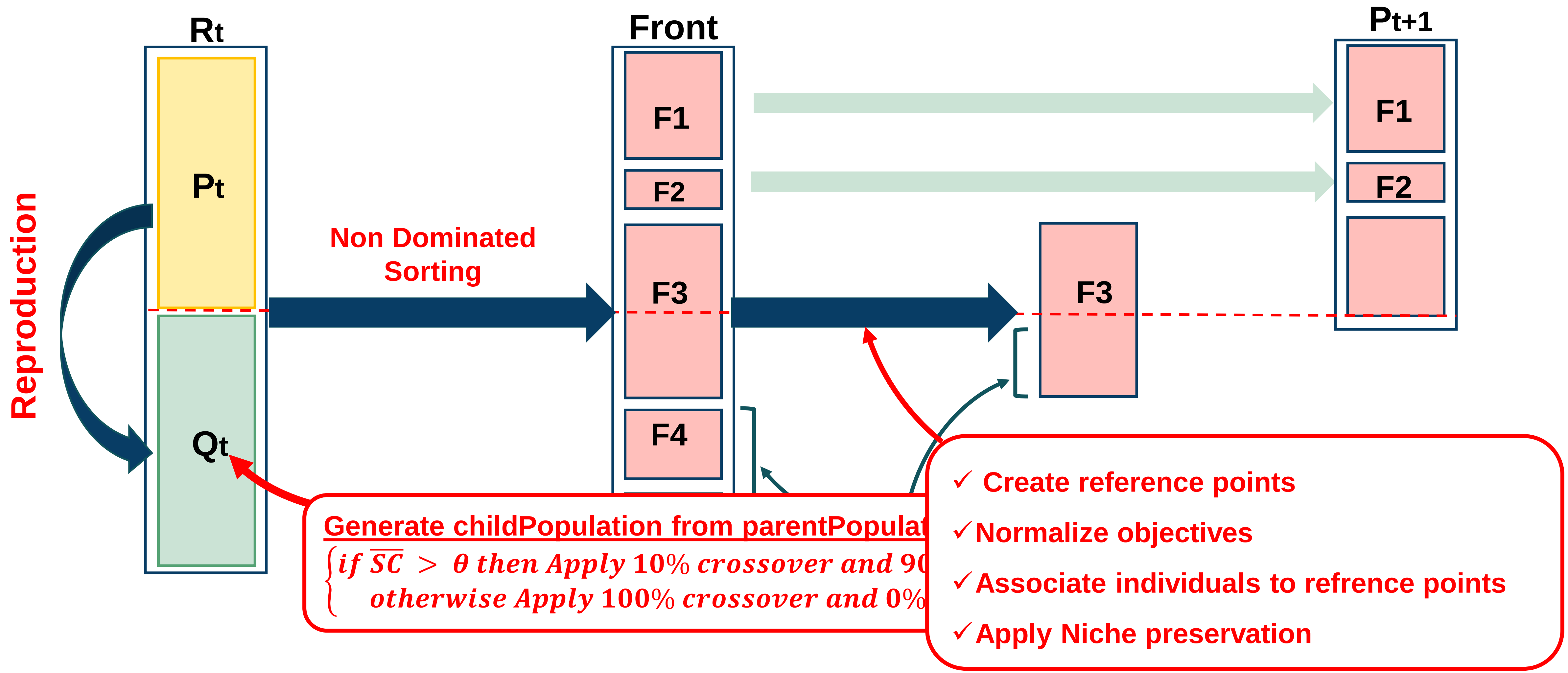
Proposed Approaches (3)

NSGA-II ⟶ SC-D-NSGA-II



Proposed Approaches (4)

NSGA-III ⟶ SC-NSGA-III



Experimental Results And Analyses (1)

Taylor & Francis
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International Journal of Production Research

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tprs20

Sustainable multi-objective process planning in reconfigurable manufacturing environment: adapted new dynamic NSGA-II vs New NSGA-III

Imen Khettabi, Lyes Benyoucef & Mohamed Amine Boutiche

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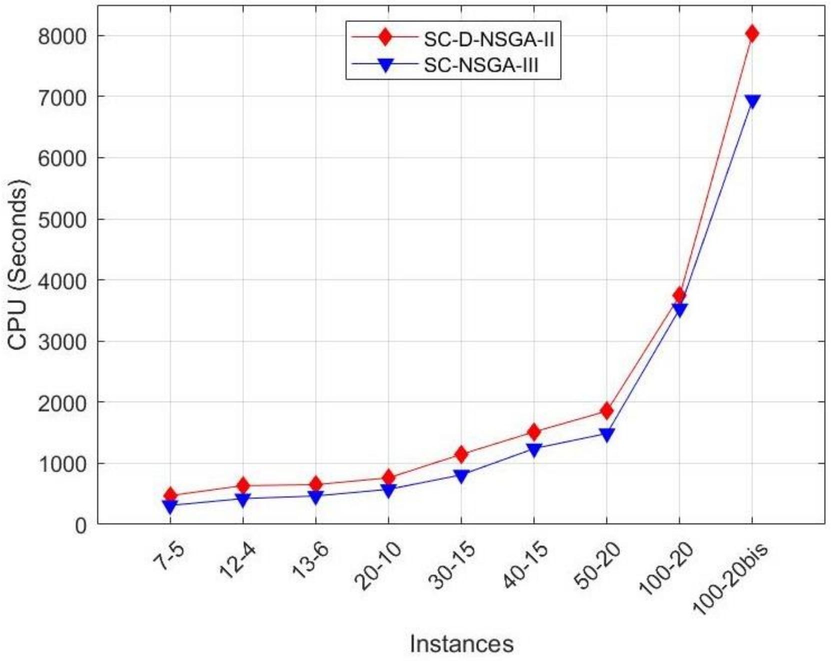
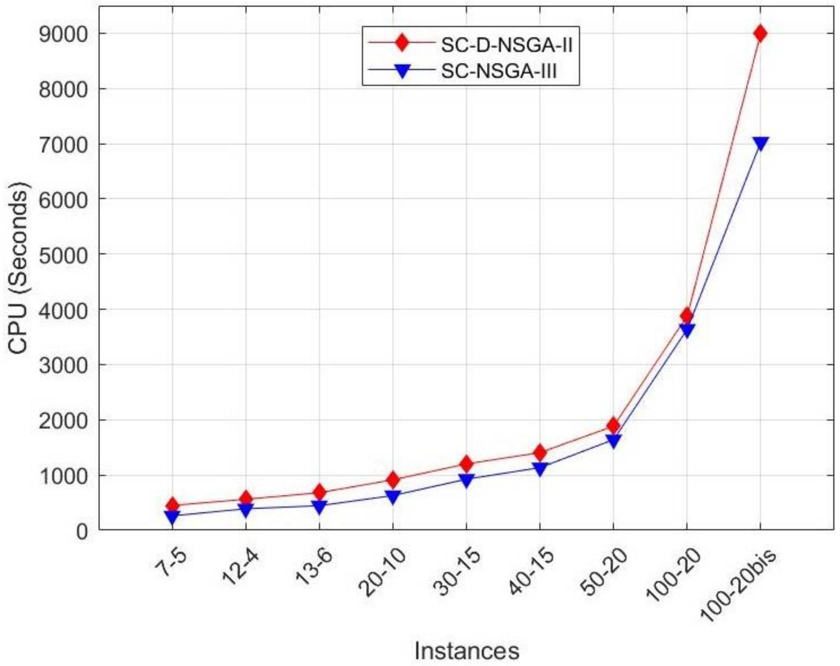
To link to this article: https://doi.org/10.1080/00207543.2022.2044537

Experimental Results And Analyses (2)
SC-D-NSGA-II vs SC-NSGA-III

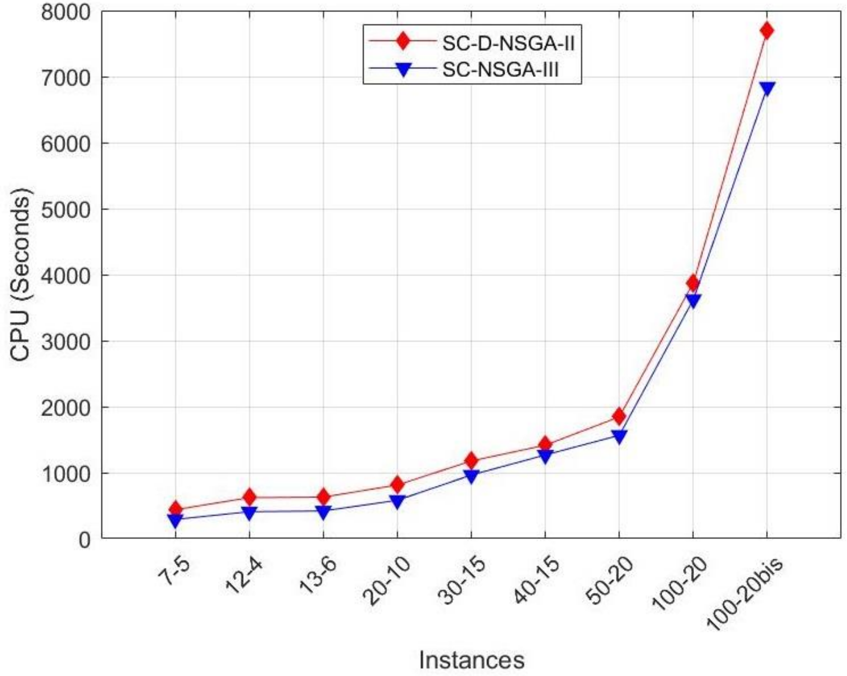
CPU calculation times of SC-D-NSGA-II vs SC-NSGA-III (Seconds)



$\theta = 0.10$



$\theta = 0.15$



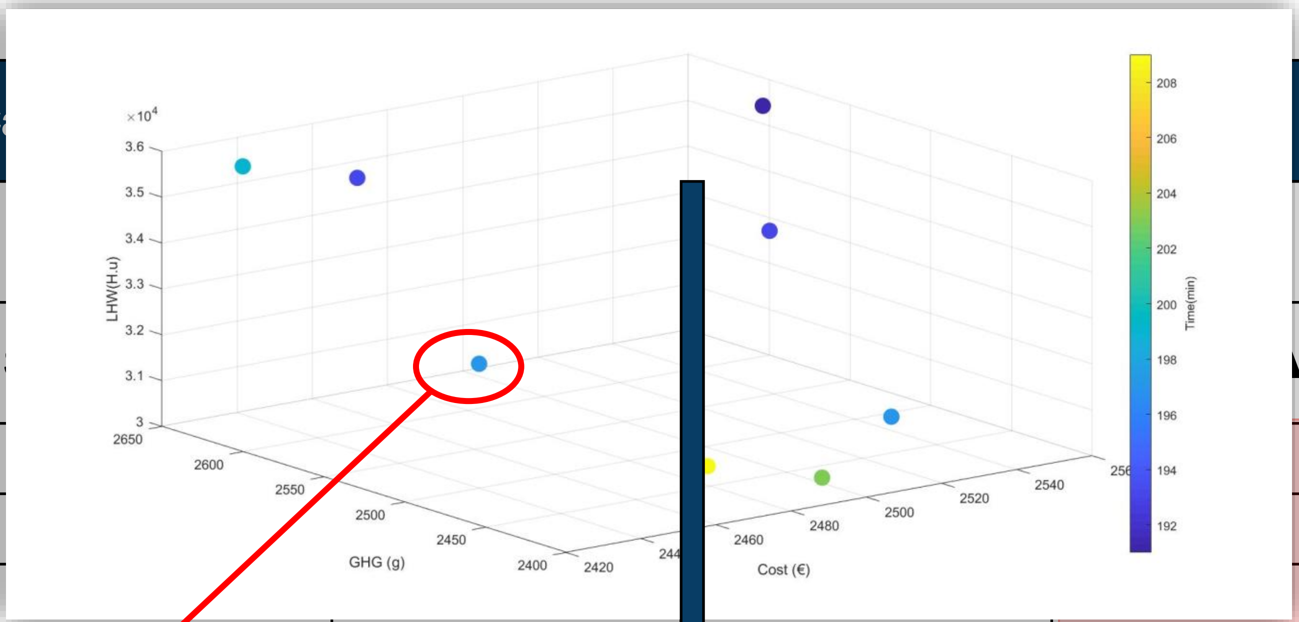
$\theta = 0.20$

Experimental Results And Analyses (3)

SC-D-NSGA-II vs SC-NSGA-III

Cardinality of the Pareto fronts of SC-D-NSGA-II vs SC-NSGA-III

Instance	θ = 0.10					
	SC-D-NSGA-II	SC-NSGA-III				
7-5	7	7				
12-4	8	14				
13-6	10	10				
20-10						15
30-15						19
4						21
5						14
1						21
100-20bis	20	16	16	18	12	24



Triplet	Operation	OP8	OP11	OP1	OP12	OP3	OP5	OP10	OP4	OP7	OP2	OP6	OP9
	Machine	M3	M3	M4	M4	M1	M4	M4	M3	M2	M2	M1	M4
	Configuration	C3	C1	C1	C1	C1	C1	C1	C1	C2	C2	C3	C1
	Tool	T2	T1	T3	T3	T2	T3	T5	T2	T1	T1	T3	T5

Experimental Results And Analyses (4)

SC-D-NSGA-II vs SC-NSGA-III

Cardinality of the mixed Pareto fronts of SC-D-NSGA-II vs SC-NSGA-III

$$\theta = 0.10$$

Instance	CMPF	# Pareto front of SC-D-NSGA-II	# Pareto front of SC-NSGA-III	# Pareto front in common
7-5	8	**4**	2	2
12-4	15	2	**13**	1
13-6	13	4	**8**	0
20-10	18	6	**12**	0
30-15	22	5	**17**	0
40-20	38	18	**20**	0
50-20	20	9	**11**	0
100-20	33	15	**18**	0
100-20bis	20	9	**11**	0

Experimental Results And Analyses (5)
SC-D-NSGA-II vs SC-NSGA-III

Cardinality of the mixed Pareto fronts of SC-D-NSGA-II vs SC-NSGA-III

$$\theta = 0.15$$

Instance	CMPF	# Pareto front of SC-D-NSGA-II	# Pareto front of SC-NSGA-III	# Pareto front in common
7-5	7	**1**	**1**	5
12-4	18	**12**	3	3
13-6	10	3	**7**	0
20-10	19	7	**12**	0
30-15	28	11	**17**	0
40-20	19	0	**19**	0
50-20	16	7	**9**	0
100-20	10	0	**10**	0
100-20bis	33	16	**17**	0

Experimental Results And Analyses (6)

SC-D-NSGA-II vs SC-NSGA-III

Cardinality of the mixed Pareto fronts of SC-D-NSGA-II vs SC-NSGA-III

$$\theta = 0.20$$

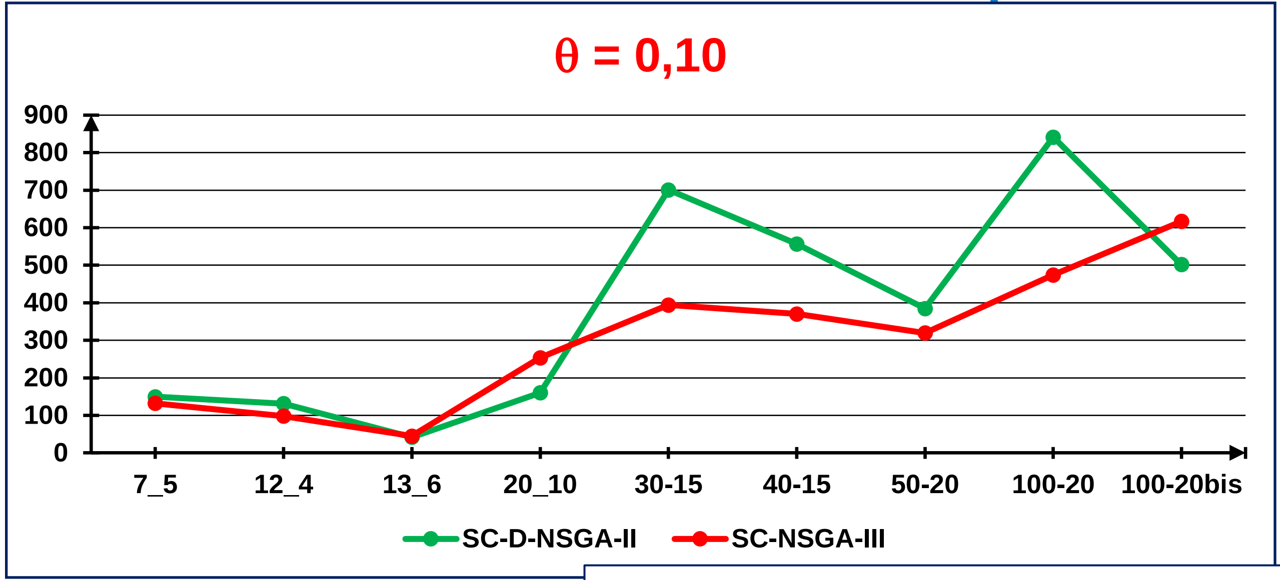
Instance	CMPF	# Pareto front of SC-D-NSGA-II	# Pareto front of SC-NSGA-III	# Pareto front in common
7-5	7	2	**4**	1
12-4	15	6	**9**	0
13-6	11	3	**6**	2
20-10	11	1	**10**	0
30-15	35	16	**19**	0
40-20	33	12	**21**	0
50-20	15	1	**14**	0
100-20	21	0	**21**	0
100-20bis	24	0	**24**	0

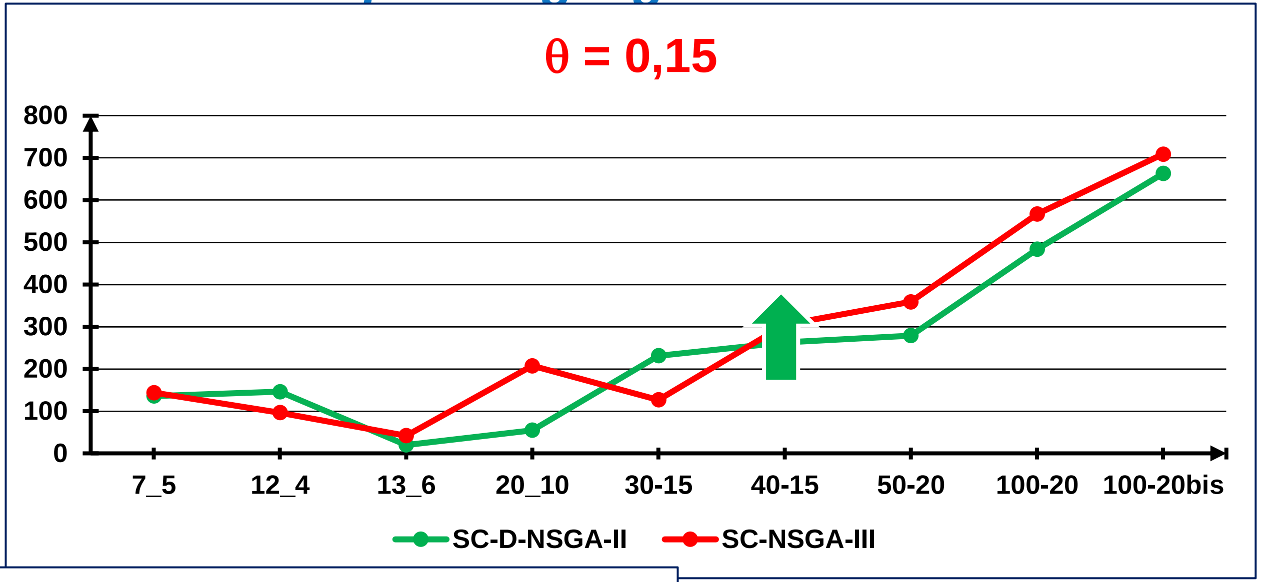
Experimental Results And Analyses (7)

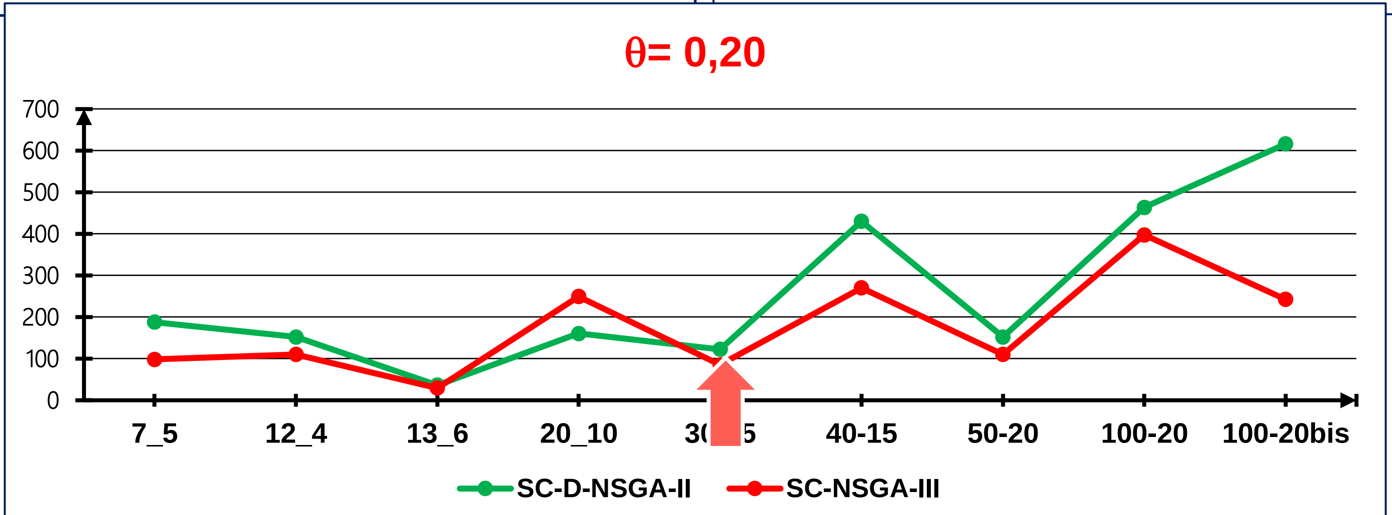
SC-D-NSGA-II vs SC-NSGA-III

IGD (Inverted Generational Distance) Metric vs Threshold Similarity Coefficient θ.

A smaller IGD value indicates a batter performance of the corresponding algorithm



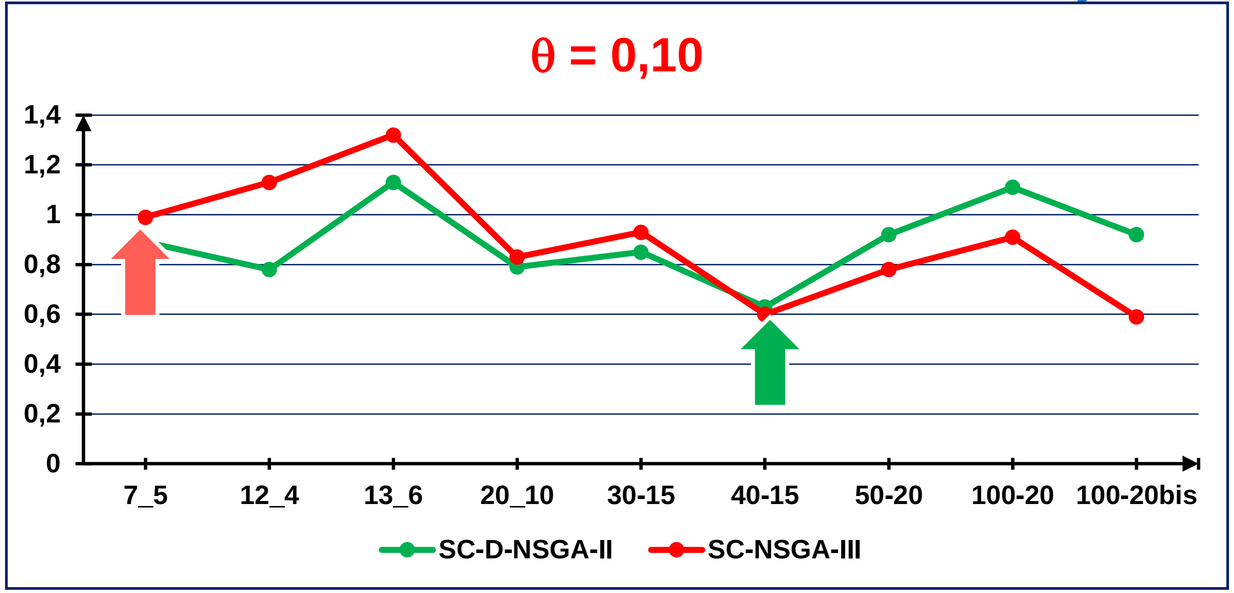


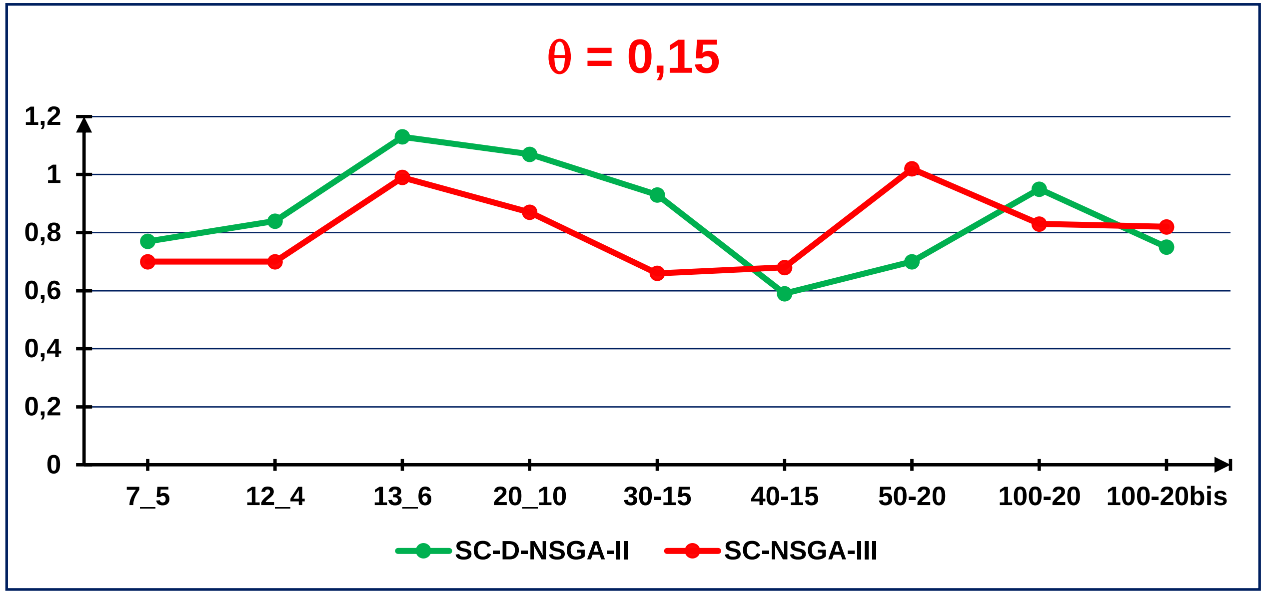


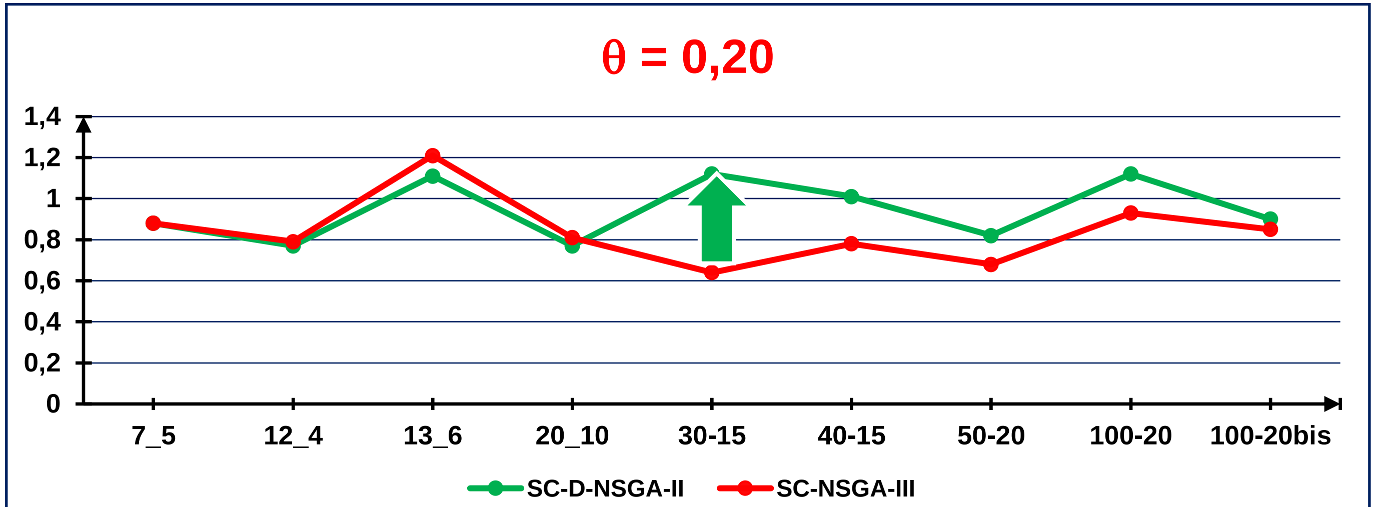
Experimental Results And Analyses (8)
SC-D-NSGA-II vs SC-NSGA-III

DM (Diversity Metric) vs Threshold Similarity Coefficient θ.

The lower value of the DM indicates a better diversity of the obtained Pareto







Sensitivity Analyses (1)

Sensitivity Analyses 1: Crossover and Mutation Impacts

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A Comparative Study of Three NSGA Versions for the Multi-Objective Sustainable Process Plans Optimization in RMS

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Available online 26 October 2022, Version of Record 26 October 2022.

Sensitivity Analyses (2)

Perturbation Ratio and Similarity Coefficient Impacts

$\theta = 0.10$

Instance	CMPF	PR=10%	PR=20%	PR=30%	PR=40%	PR=50%
100-20bis1	33	0	0	**18**	15	0
100-20bis2	34	15	2	**16**	1	0
100-20bis3	32	16	0	**16**	0	0
100-20bis4	30	10	0	**20**	0	0
100-20bis5	25	8	0	**17**	0	0

$\theta = 0.15$

Instance	CMPF	PR=10%	PR=20%	PR=30%	PR=40%	PR=50%
100-20bis1	21	2	3	**10**	0	6
100-20bis2	42	13	11	**18**	0	0
100-20bis3	23	4	1	**15**	0	3
100-20bis4	19	0	0	**19**	0	0
100-20bis5	17	0	0	**17**	0	0

$\theta = 0.20$

Instance	CMPF	PR=10%	PR=20%	PR=30%	PR=40%	PR=50%
100-20bis1	26	0	0	**21**	0	5
100-20bis2	40	0	3	**24**	0	13
100-20bis3	26	0	0	**16**	0	10
100-20bis4	23	0	0	**19**	0	4
100-20bis5	20	0	0	**14**	0	6

Sensitivity Analyses (3)
Similarity Coefficient Impacts

Cardinality of the mixed Pareto front of SC-NSGA-III

Instance	CMPF	# Pareto front of SC-NSGA-III			
		θ = 0.10	θ = 0.15	θ = 0.20	# Pareto front in common
7-5	8	**3**	2	1	4
12-4	19	**12**	5	2	0
13-6	12	**9**	6	2	1
20-10	16	**13**	0	3	0
30-15	31	12	0	**19**	0
40-15	36	8	11	**17**	0
50-20	30	7	9	**14**	0
100-20	26	2	3	**21**	0
100-20bis	32	8	0	**24**	0

Sensitivity Analyses (4)
TOPSIS Weights Impacts

Cardinality of the mixed Pareto front of SC-NSGA-III

Instance	CMPF	# Pareto front of SC-NSGA-III			
		$\theta = 0.10$	$\theta = 0.15$	$\theta = 0.20$	# Pareto front in common
7-5	8	3	2	1	4
12-4	19	12	5	2	0
13-6	12	9	6	2	1
20-10	16	13	0	3	0
30-15	31	12	0	19	0
40-15	36	8	11	17	0
50-20	30	7	9	14	0
100-20	**26**	**2**	**3**	**21**	0
100-20bis	32	8	0	24	0

Sensitivity Analyses (5)
TOPSIS Weights Impacts

<u>Note</u>: The process plan PP_6 obtained by SC-NSGA-III for **θ = 0.20** emerged as the preferred solution

Scenario 1 | Scenario 2 | Scenario 3

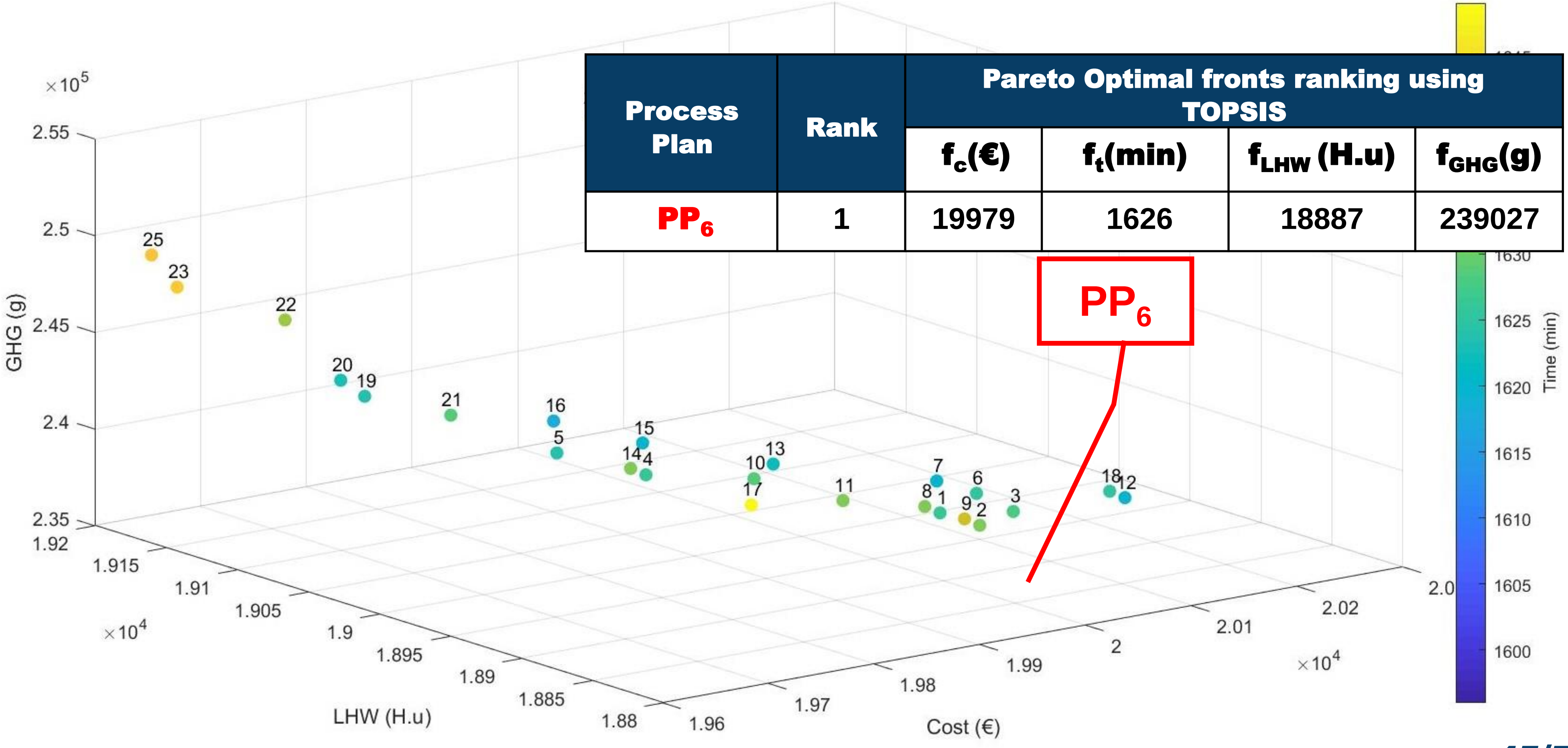
$W_{f_c} = 0.25$

$W_{f_t} = 0.25$

$W_{f_{GHG}} = 0.25$

$W_{f_{LHW}} = 0.25$

Process Plan	Rank	Pareto Optimal fronts ranking using TOPSIS			
		f_c(€)	f_t(min)	f_{LHW} (H.u)	f_{GHG}(g)
PP_6	1	19979	1626	18887	239027



Sensitivity Analyses (6)
TOPSIS Weights Impacts

Note: The process plan **PP$_{11}$** obtained by SC-NSGA-III for **θ = 0.20** emerged as the preferred solution

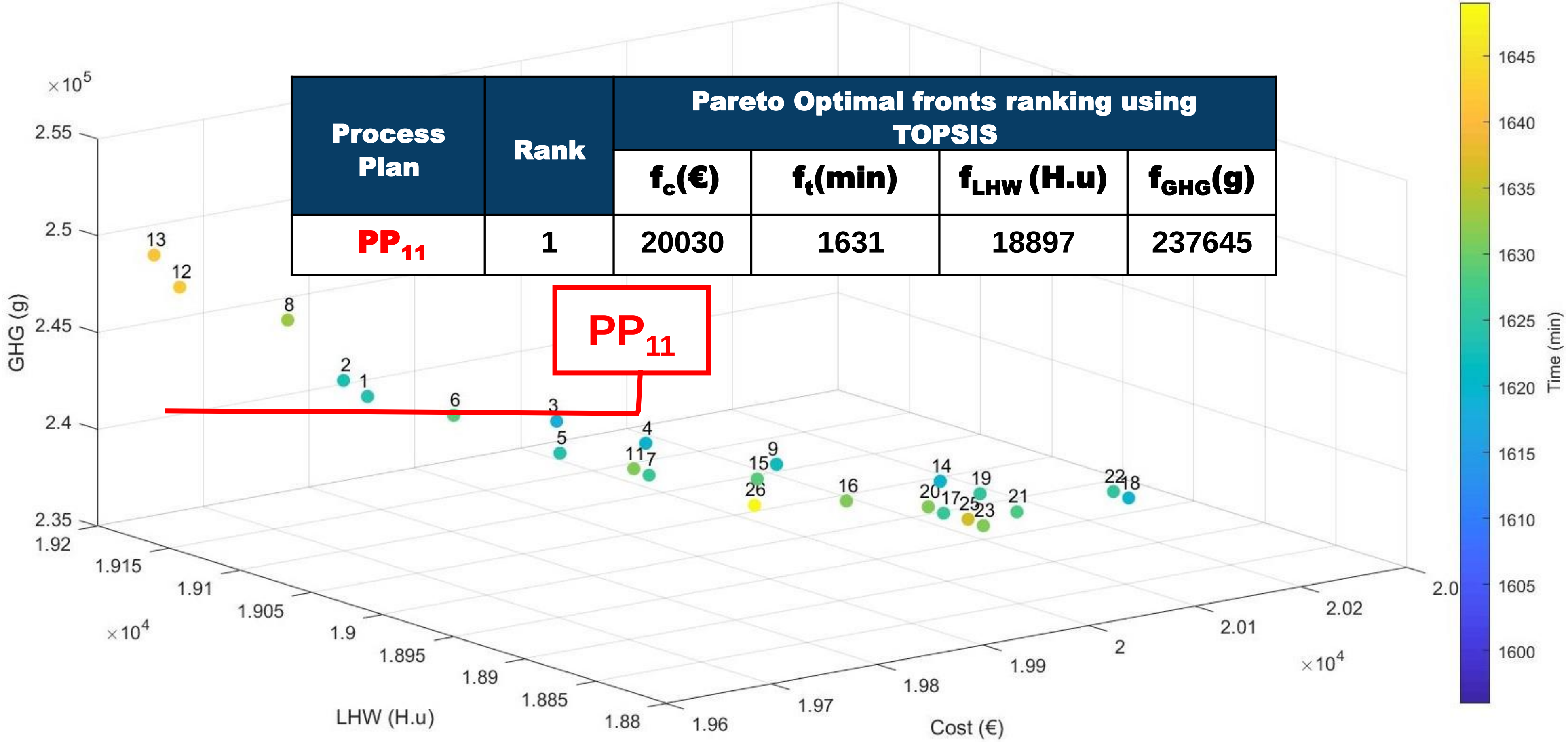
$$W_{f_c} = 0.10$$

$$W_{f_t} = 0.10$$

$$W_{f_{GHG}} = 0.40$$

$$W_{f_{LHW}} = 0.40$$

Process Plan	Rank	Pareto Optimal fronts ranking using TOPSIS			
		f_c(€)	f_t(min)	f_{LHW} (H.u)	f_{GHG}(g)
PP$_{11}$	1	20030	1631	18897	237645



Sensitivity Analyses (7)
TOPSIS Weights Impacts

Note: The process plan **PP$_{18}$** obtained by SC-NSGA-III for **θ = 0.20** emerged as the preferred solution

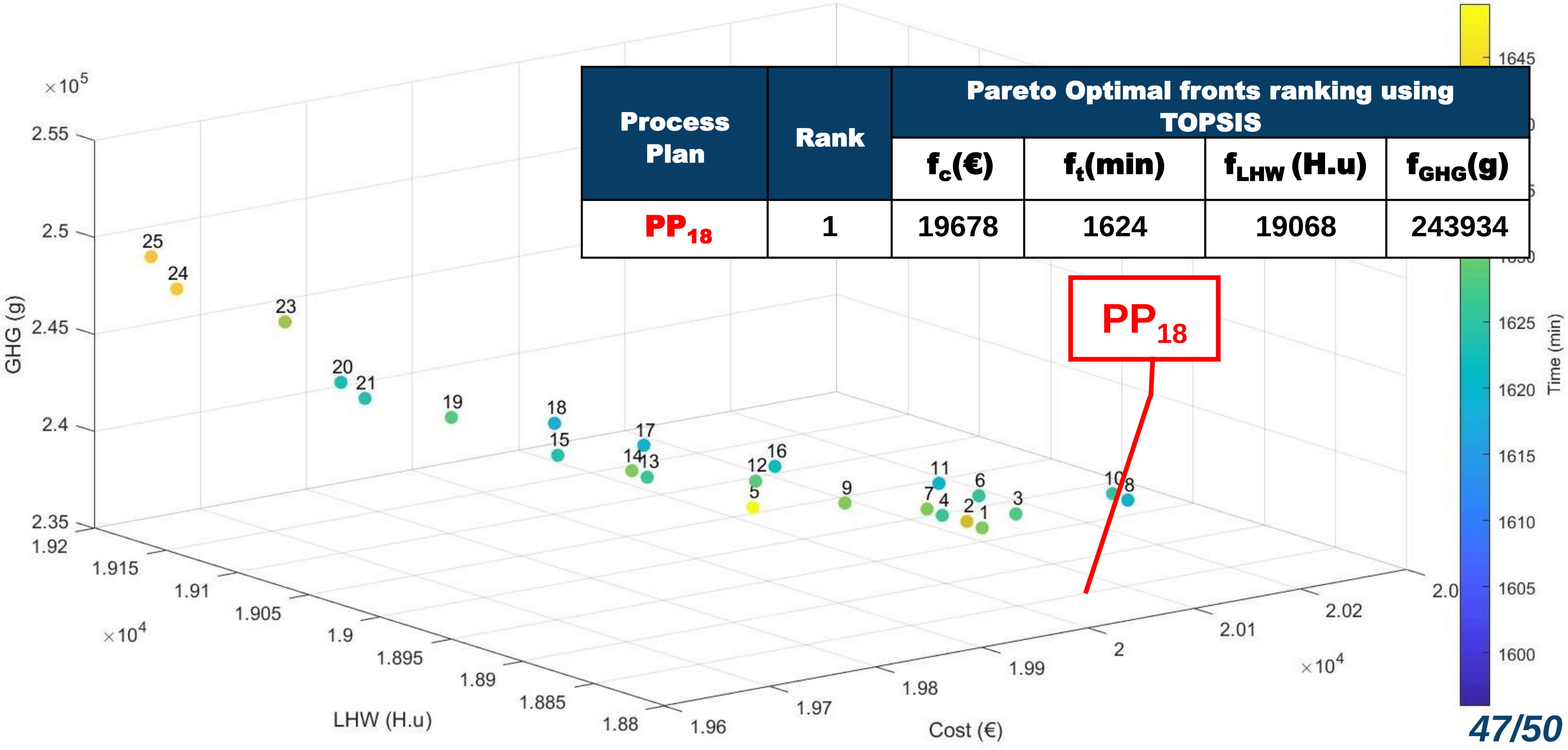
$W_{f_c} = 0.40$

$W_{f_t} = 0.40$

$W_{f_{GHG}} = 0.10$

$W_{f_{LHW}} = 0.10$

Process Plan	Rank	Pareto Optimal fronts ranking using TOPSIS			
		f_c(€)	f_t(min)	f_{LHW} (H.u)	f_{GHG}(g)
PP$_{18}$	1	19678	1624	19068	243934



Conclusion

- Sustainability and Reconfigurable Manufacturing Systems (RMSs)
- Non-Linear Muti-Objective Integer Program (NL-MOIP)
- WGA, RWGA, SPEA-II, NSGA-II, DNSGA- II, R-NSGA-II, PBI-R-NSGA-II, SC-D-NSGA-II, NSGA-III, SE-NSGA-III, SC-NSGA-III.
- Experimental Results and Analyses: SC-D-NSGA-II vs SC-NSGA-III
- Sensitivity Analyses 1: Perturbation Ratio and Similarity Coefficient Impacts
  Sensitivity Analyses 2: TOPSIS Weights Impacts
  Sensitivity Analyses 3: Similarity Coefficient Impacts

Perspectives (1)
Approaches

Single unit process plan generation:

- The reduction of the maximum exploitation time of the machines can be considered as a new optimization criterion for the production of high quality products.

- Integration of process plan generation and scheduling problems in a reconfigurable manufacturing environment (S-IPPS : sustainable integrated process planning and scheduling).

Multi unit process plan generation:

Hybrid metaheuristics for the multi-objective multi-unit process plan generation in a reconfigurable manufacturing environment such as:

- Local search algorithm.
- Tabu search.
- …

Perspectives (2)
Approaches

Exacts approaches:

- LP metric
- Ɛ-Constraint,
- Lagrangien relaxation
- …

Meta-heuristic approaches:

- Multi Objective Particle Swarm Optimization (MOPSO).
- Archived Multi-objective Simulated Annealing Approach (AMOSA).
- Whale optimization algorithm (WOA).
- Simulation methods.
- …

Thank you for the Attention