Optimization of advanced materials handling processes in the automotive industry

- smart scheduling of milkrun supply-

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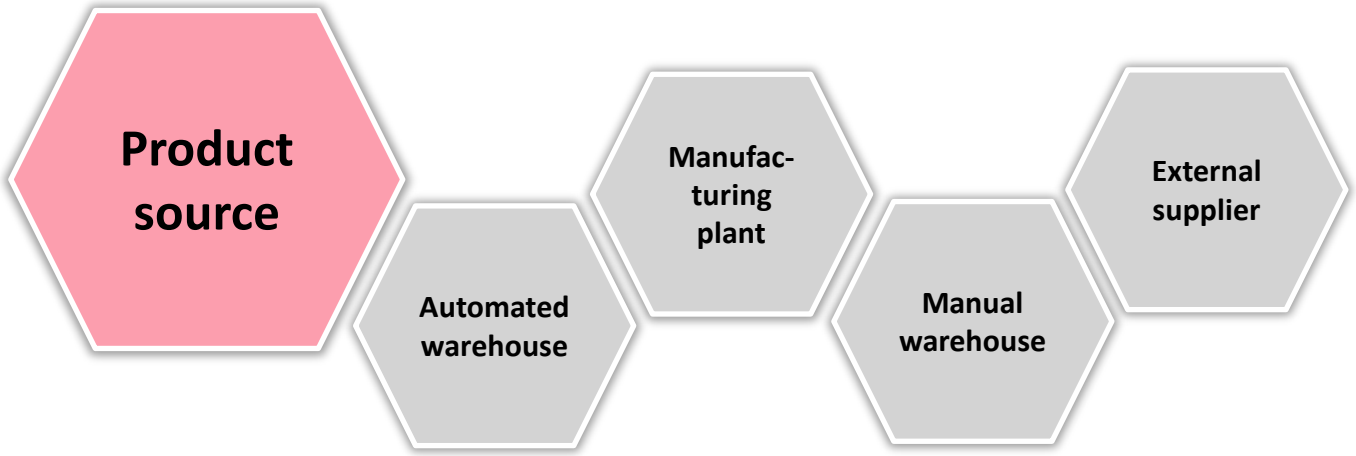
Core parameters of milkrun based in-plant supply



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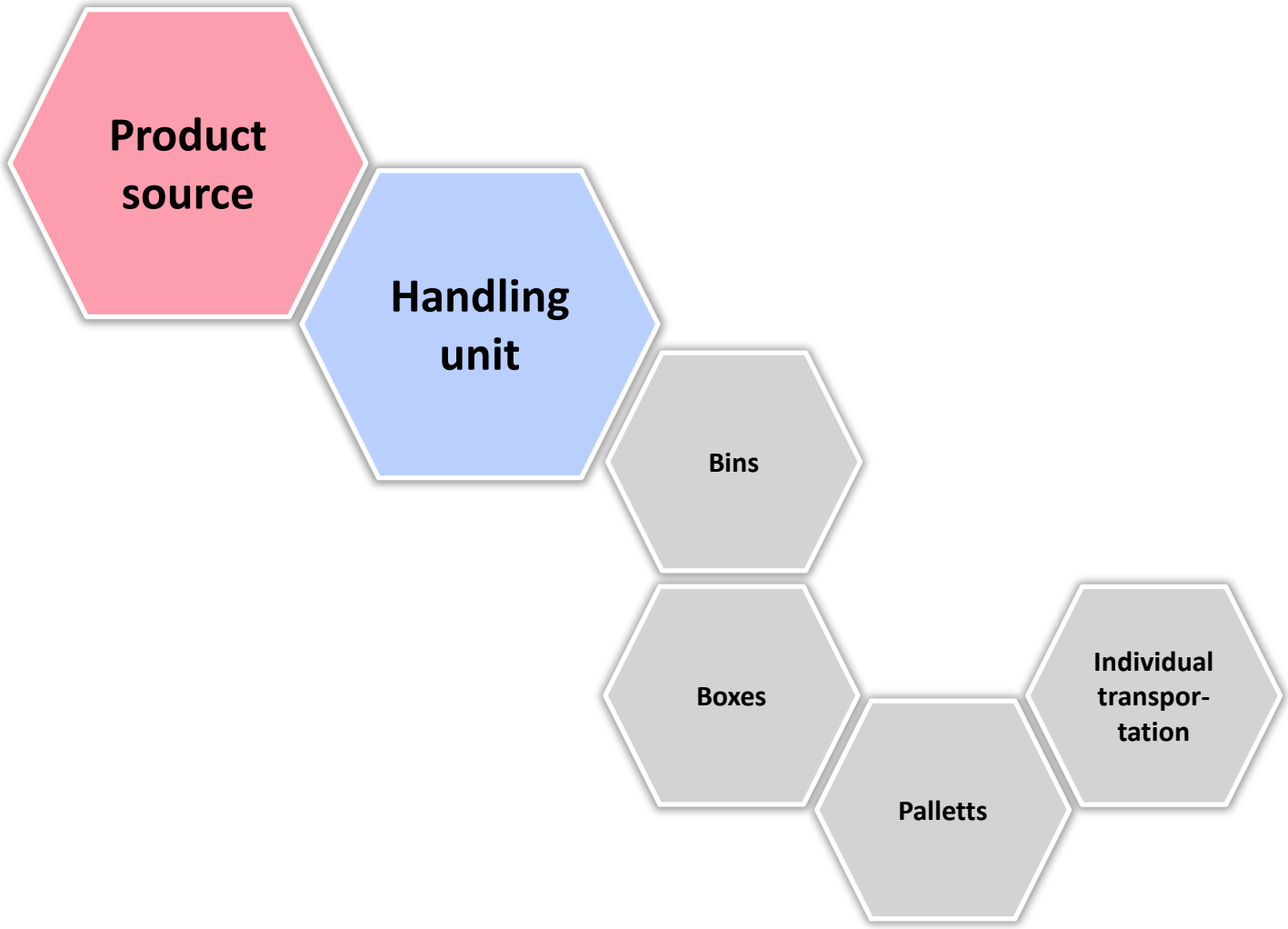

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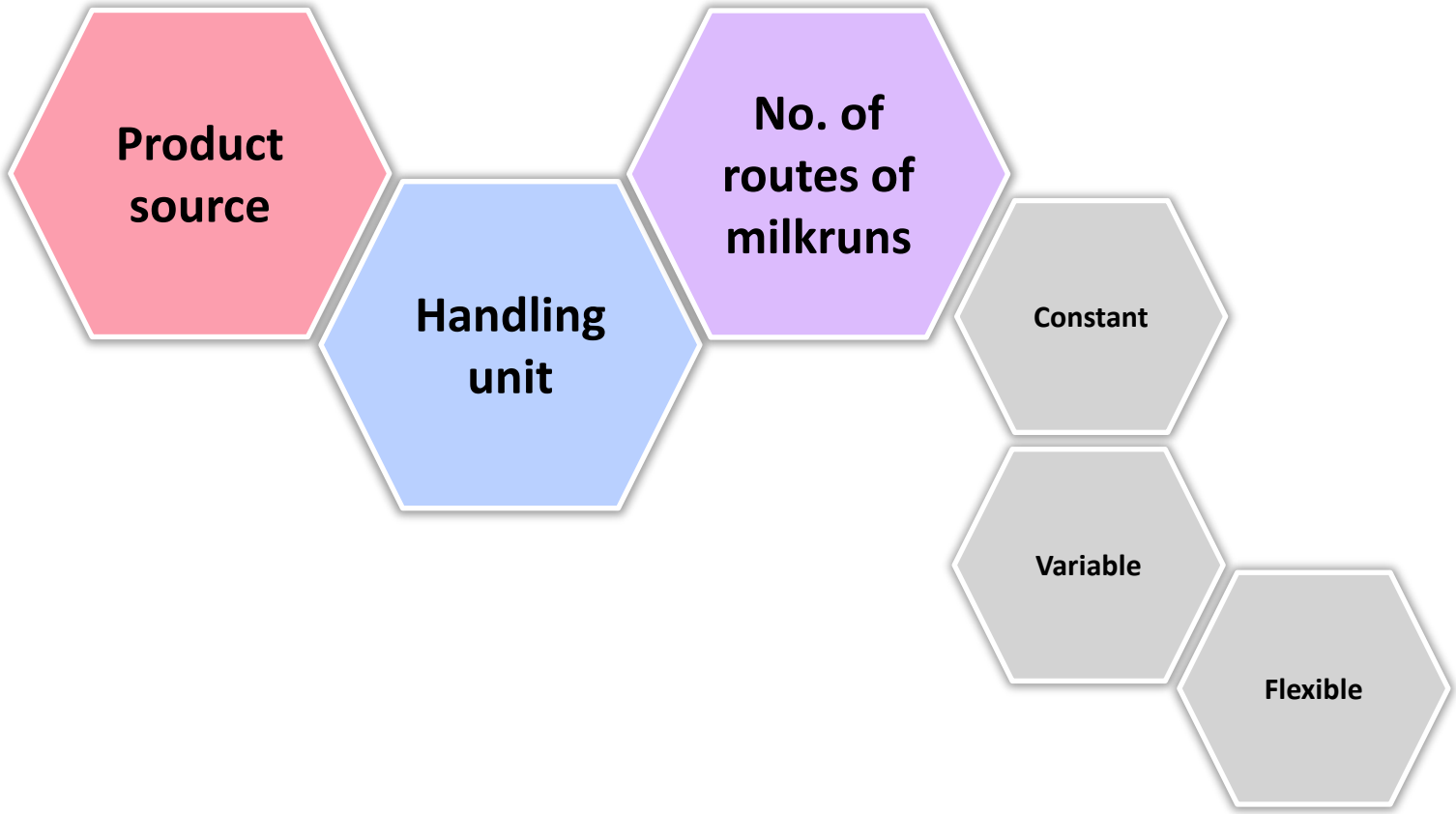

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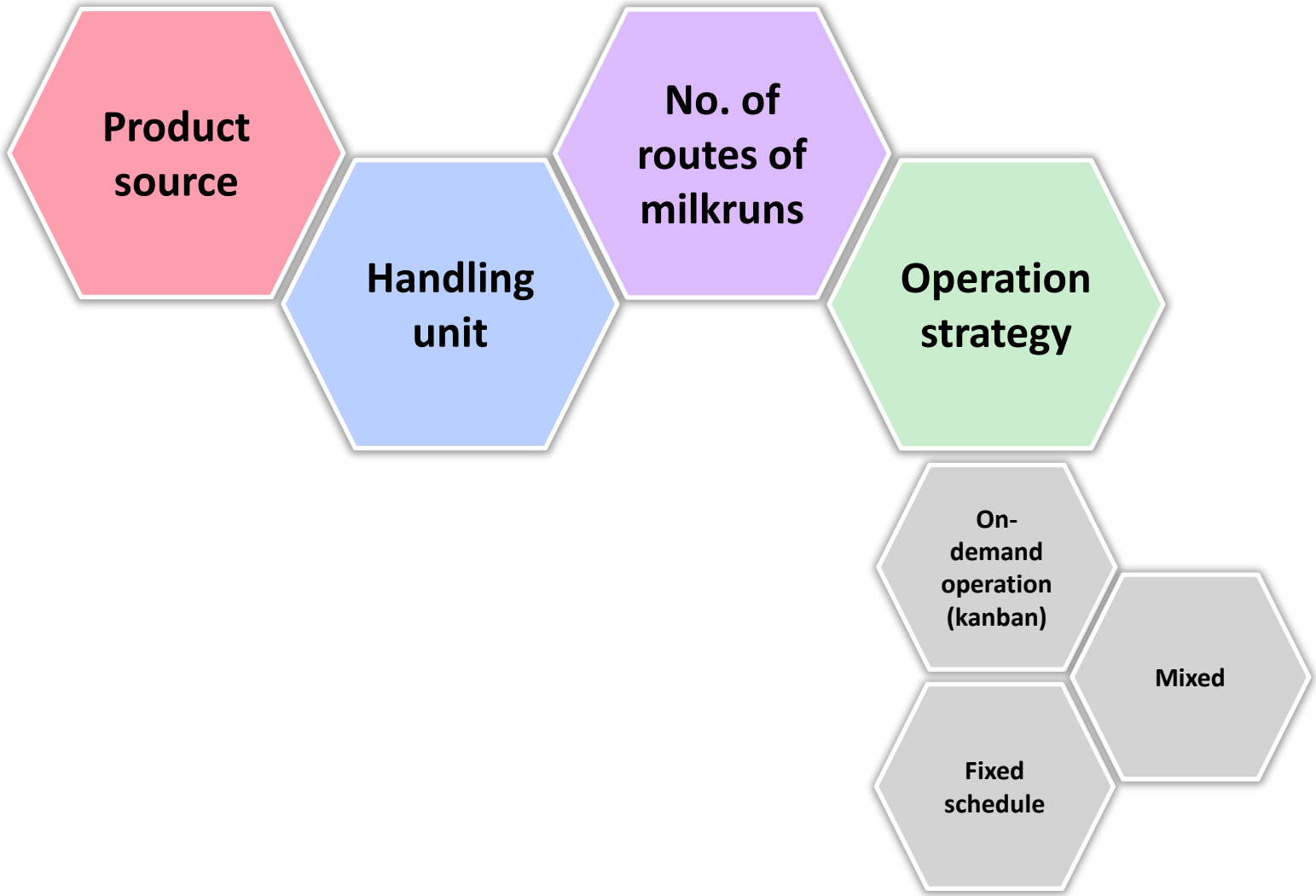

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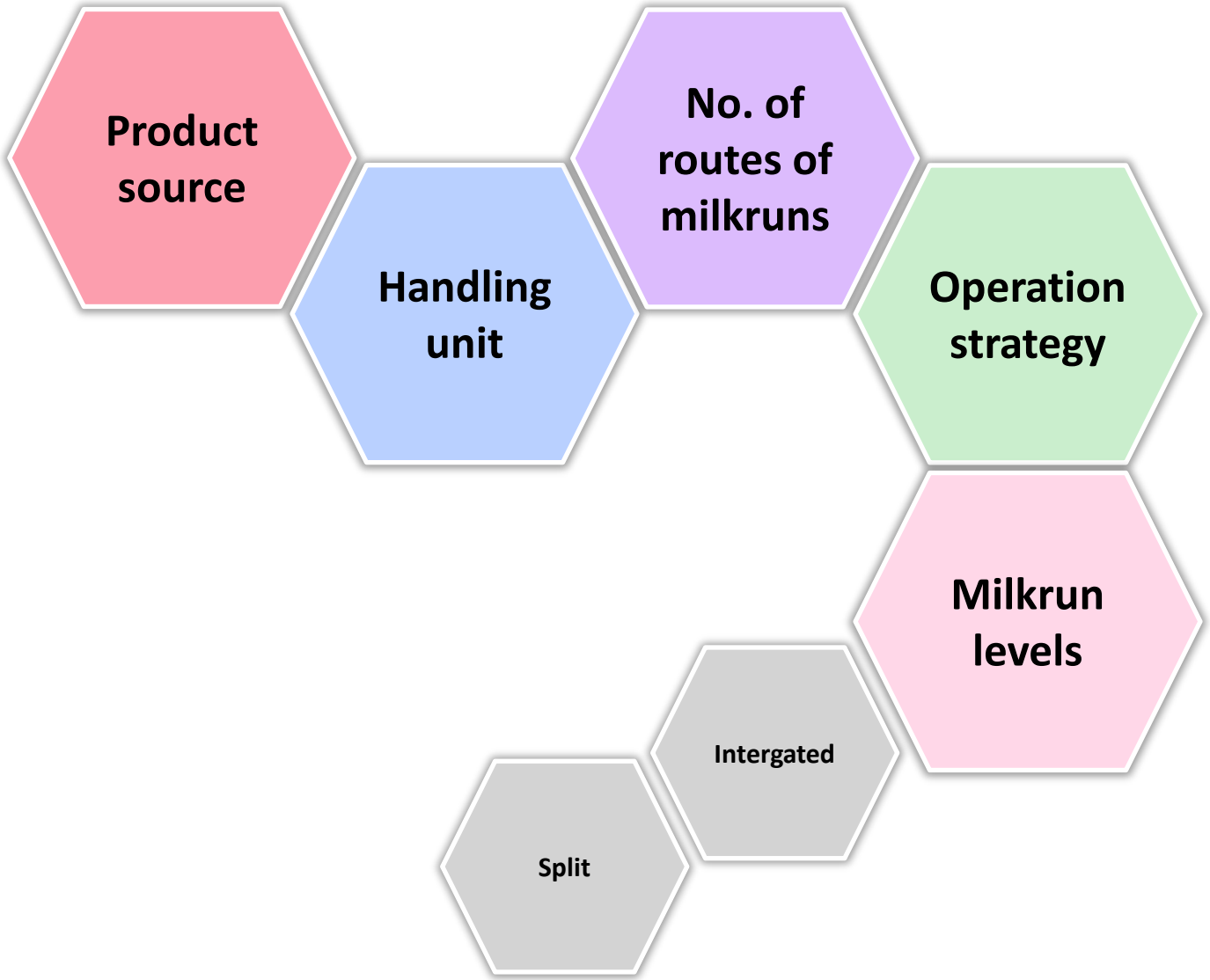

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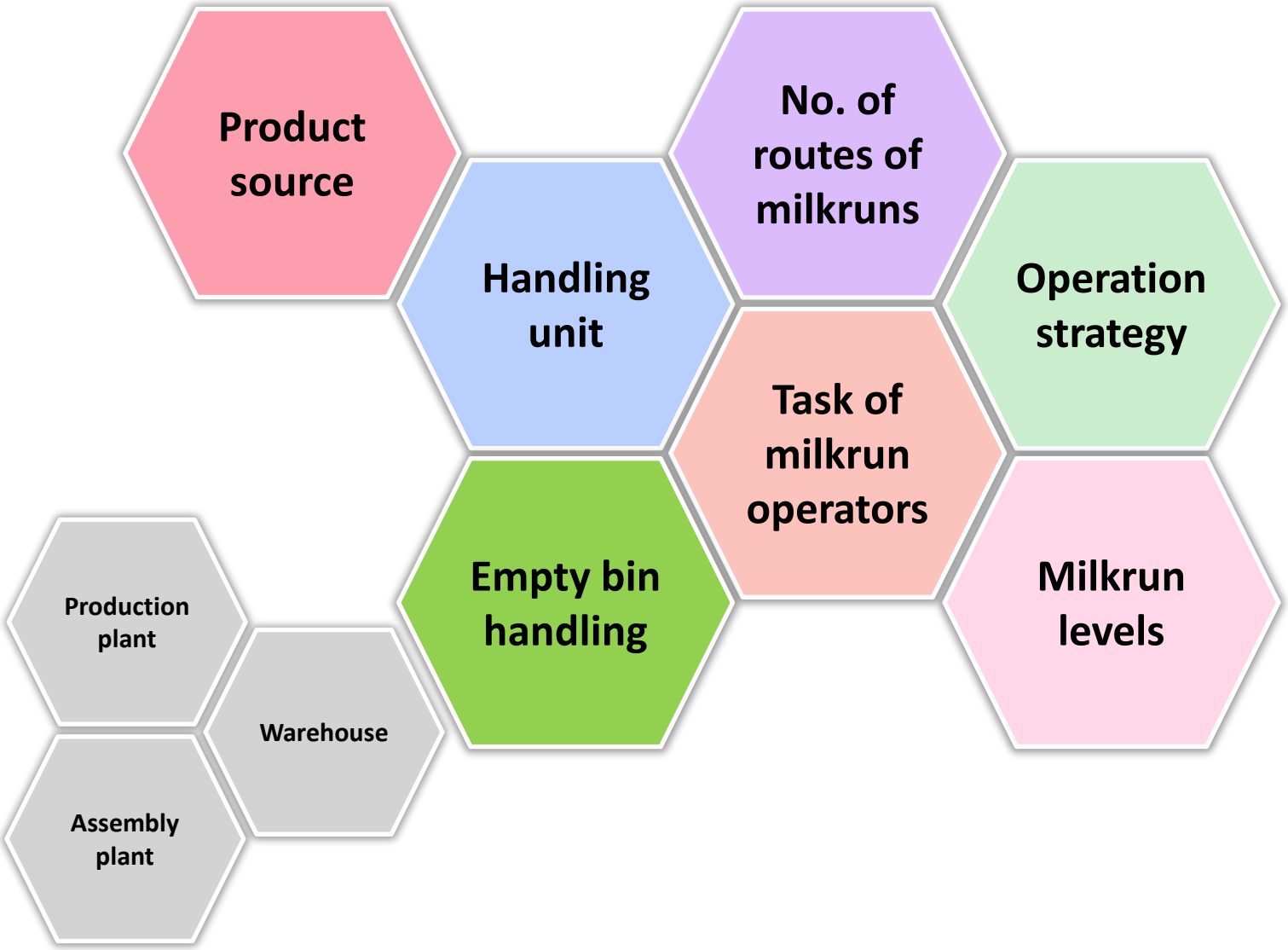

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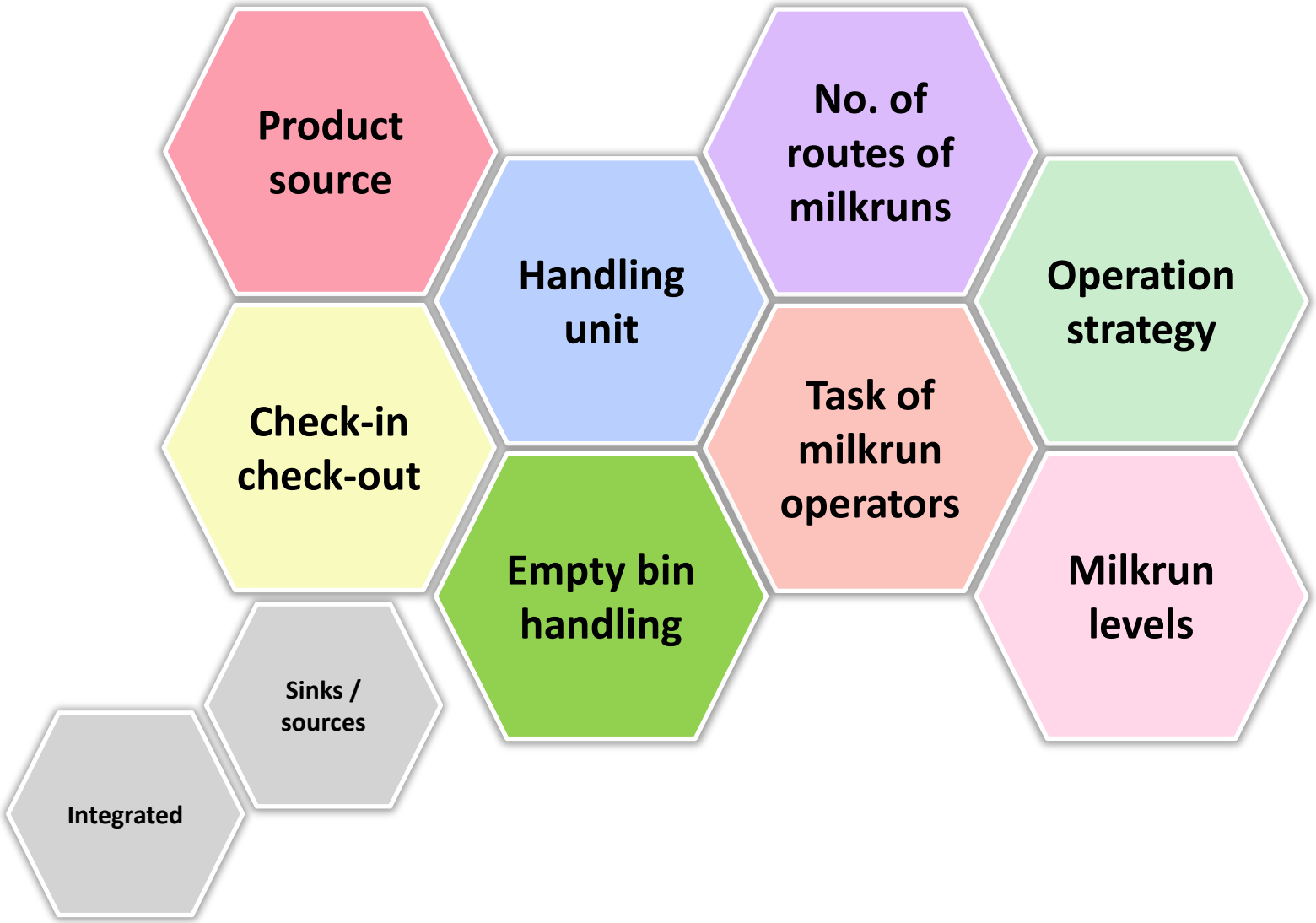

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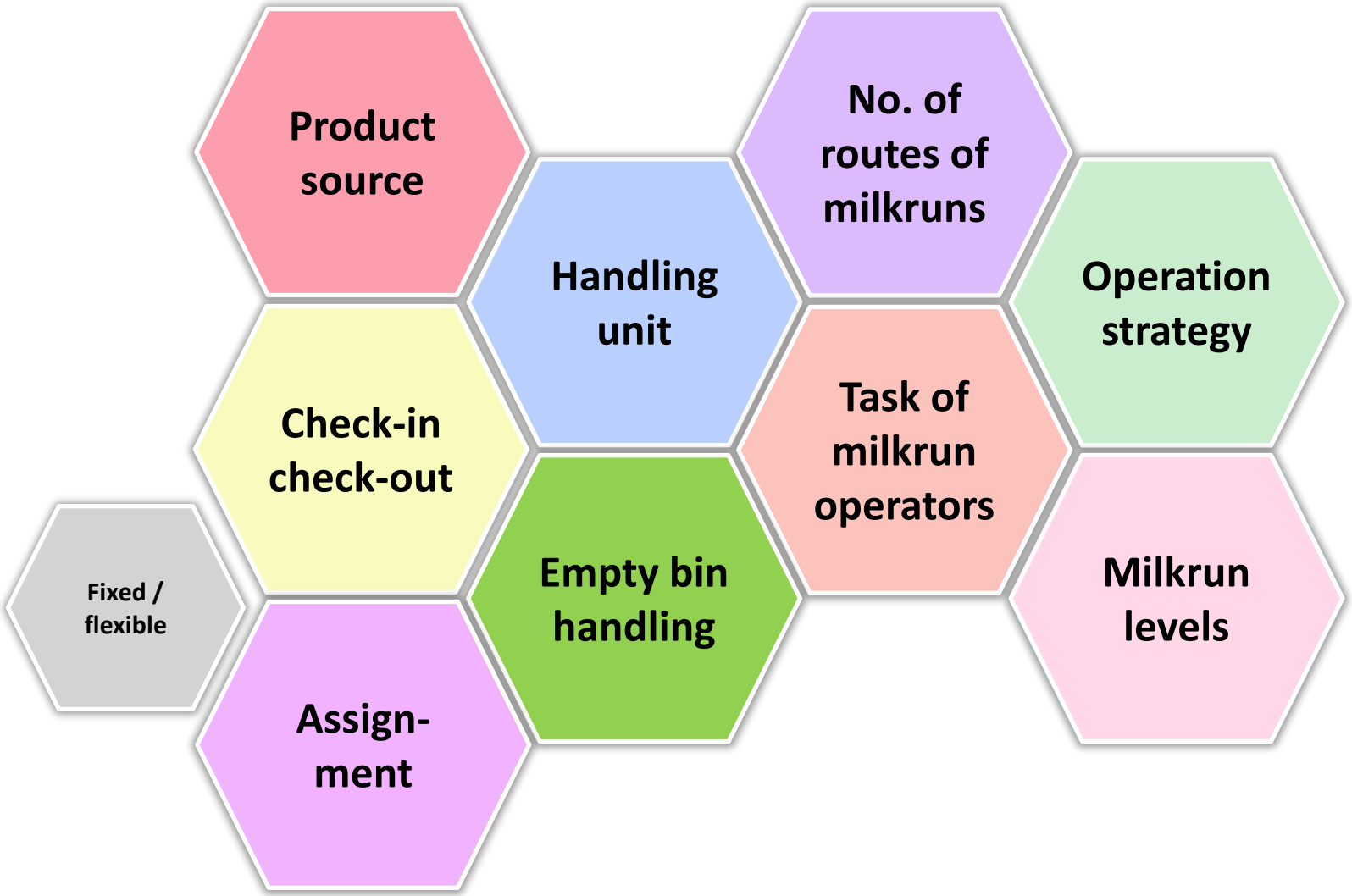
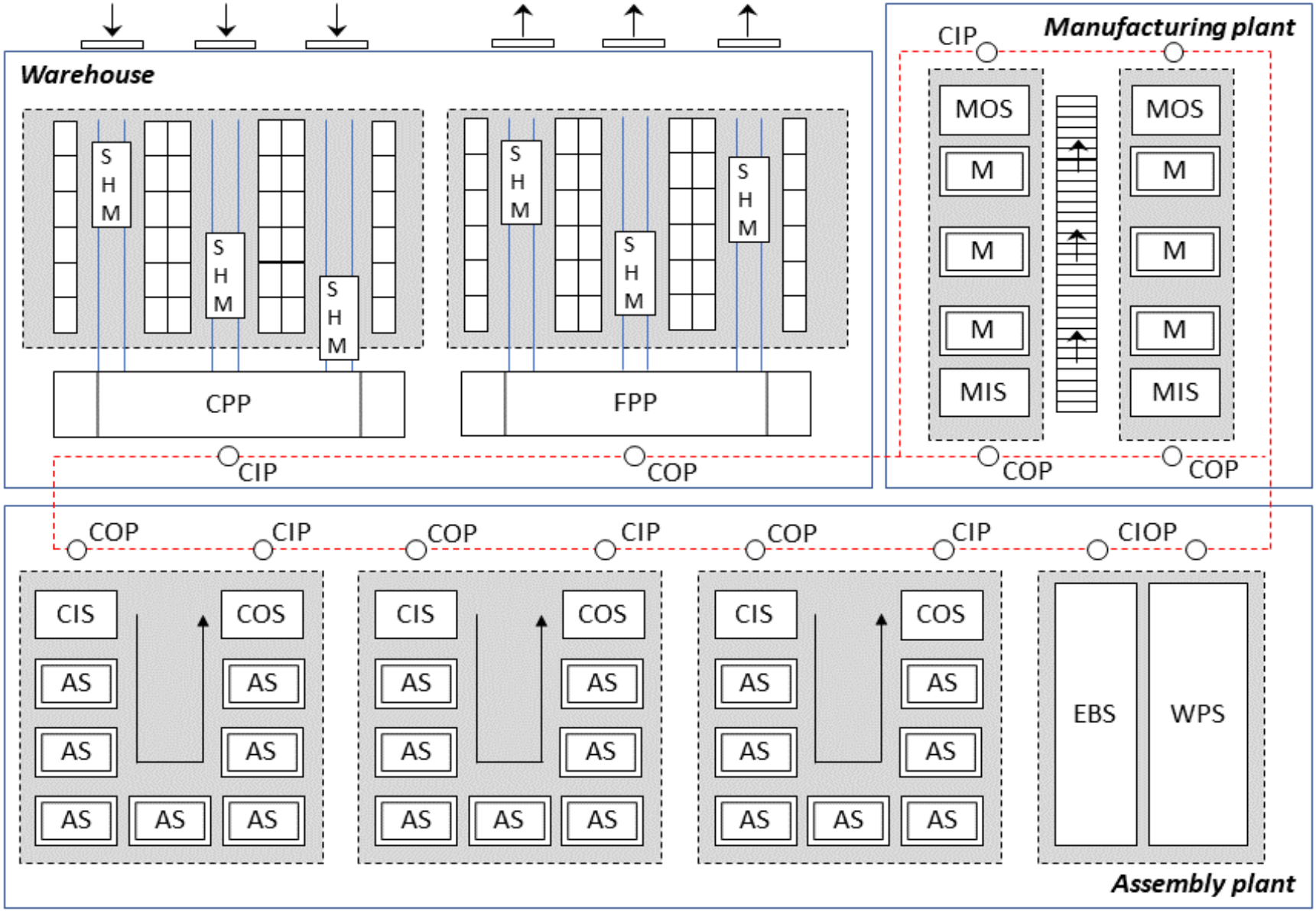
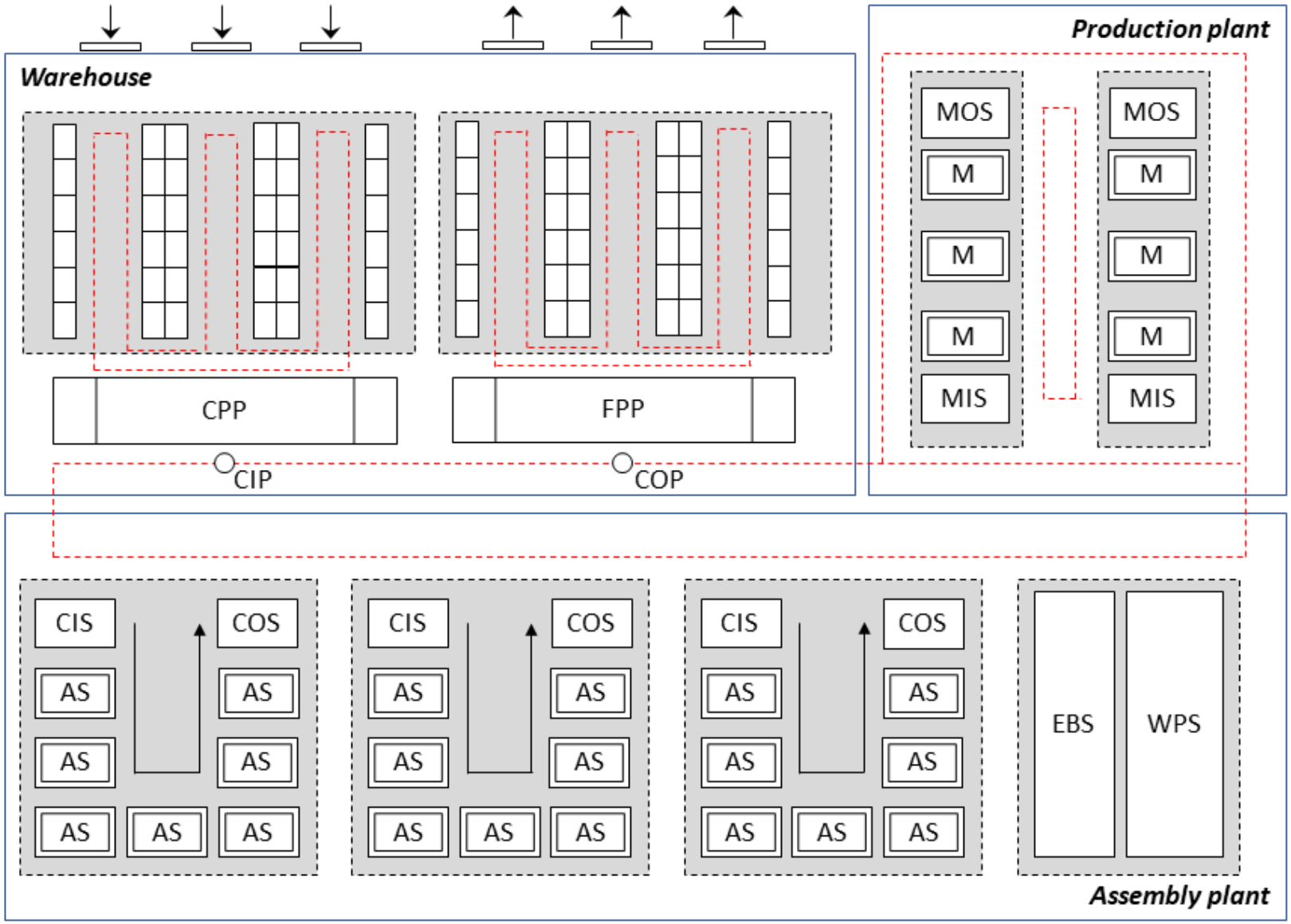


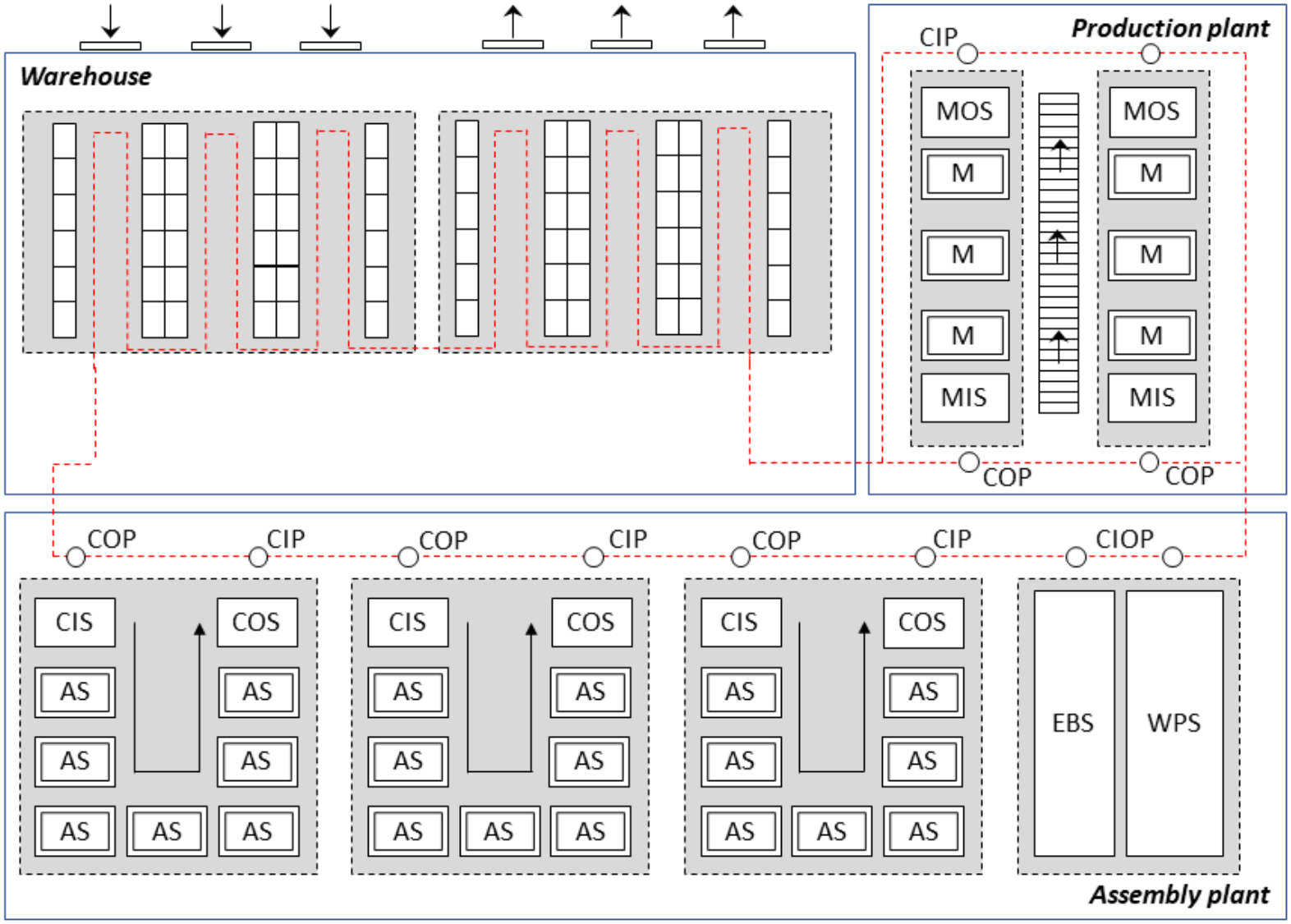
Assembly plant supply with external milkrun and decentralized check-in and check-out



Assembly plant supply with multiple milkrun and centralized check-in and check-out



Assembly plant supply with integrated milkrun and decentralized check-in and check-out



Assembly plant supply with external milkrun and decentralized check-in and check-out

Loading time of the required components at the output storage of the manufacturing cells

$$t^2_{ma,l} = \sum_{p\in\Theta} n^l_p (t^l_p + t^{ci}_p),$$

specific loading time at the input storage of manufacturing cells

specific check-out time at the input storage of manufacturing cells

Loading and unloading time of the required components at the pick-up point of the final products' warehouse

$$t^3_{w,l} = \sum_{w\in\Psi} n^l_w (t^l_w + t^{ci}_w) \qquad t^3_{w,ul} = \sum_{w\in\Psi} n^{ul}_w (t^{ul}_w + t^{co}_w),$$

specific loading time at the pick-up point of the final products' warehouse

specific loading time at the pick-up point of the final products' warehouse

specific check-in time at the pick-up point of the final products' warehouse

the specific check-in time at the pick-up point of the final products' warehouse

Transportation time among the pick-up points of the warehouse

$$t^3_{w,tr} = \sum_{s,t\in\Psi} l_{s,t}/v_{s,t},$$

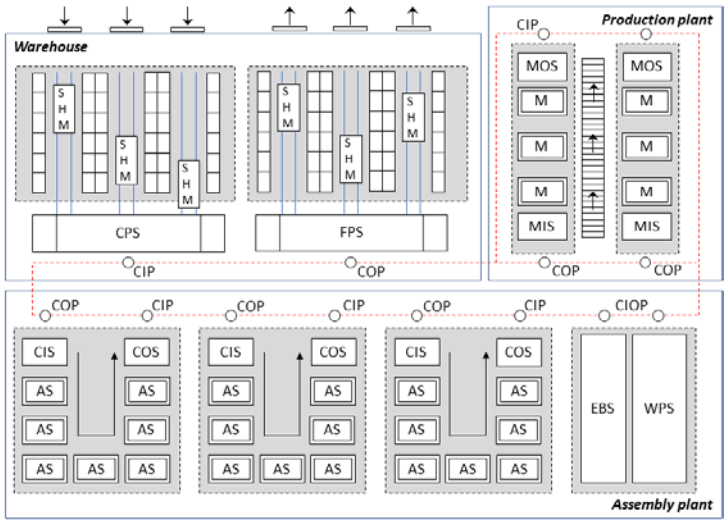
length of the transportation route among the pick-up point

the transportation speed of milkrun

set of pick-up points at the warehouse

Total cycle time of the external milkrun

$$t_{ext} = t_{add} + \sum_{y=1}^{3} t^y_{w,tr} + t^y_{w,ul} + t^y_{w,l}$$



Assembly plant supply with external milkrun and decentralized check-in and check-out

Transportation time among assembly cells

$$t^1_{as,tr} = \sum_{i,j\in\Gamma} l_{i,j}/v_{i,j}$$

length of the transportation route among assembly cells

speed of milkruns

set of assembly cells

The loading and unloading time of the required components at the u-cells' input storages

$$t^1_{as,ul} = \sum_{k\in\Gamma} n^{ul}_k (t^{ul}_k + t^{co}_k), \qquad t^1_{as,l} = \sum_{k\in\Gamma} n^{l}_k (t^{l}_k + t^{ci}_k)$$

specific unloading time at the input storage of u-shaped assembly cells

the specific check-in time at the output storage of u-shaped assembly cells

the specific check-in time at the output storage of u-shaped assembly cells

specific loading time at the input storage of u-shaped assembly cells

The transportation time among the input and output storages of manufacturing cells

$$t^2_{ma,tr} = \sum_{m,n\in\Theta} l_{m,n}/v_{m,n} + \sum_{q,r\in\Xi} l_{q,r}/v_{q,r}$$

length of the transportation route among the input storages of manufacturing cells

speed of milkruns

set of input storages of manufacturing cells

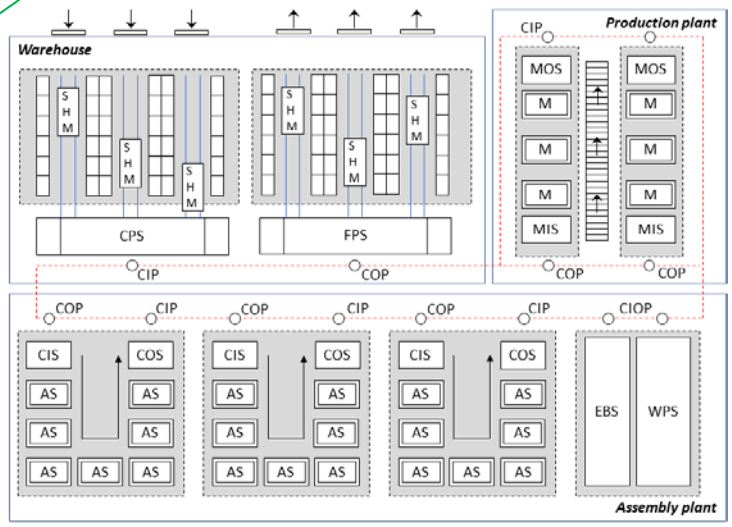
set of output storages of manufacturing cells

The unloading time of the required components at the input storage of the manufacturing cells

$$t^2_{ma,ul} = \sum_{p\in\Theta} n^{ul}_p (t^{ul}_p + t^{co}_p),$$

specific unloading time at the input storage of manufacturing cells

specific check-out time at the input storage of manufacturing cells



Comparison of different strategies in milkrun based supply domain

Operation time [s]	Transportation	Loading/Unloading	Check-in/Check-out
Manufacturing	72,0		
Input storage	-	27	14
Output storage	-	31	16
Assembly	68,4		
Input storage	-	21	20
Output storage	-	18	22
Warehouse	60,0		
Component	-	40	78
Final product	-	50	56
Additional	102,0		
EBS+WPS	27,6	45	30

914 s

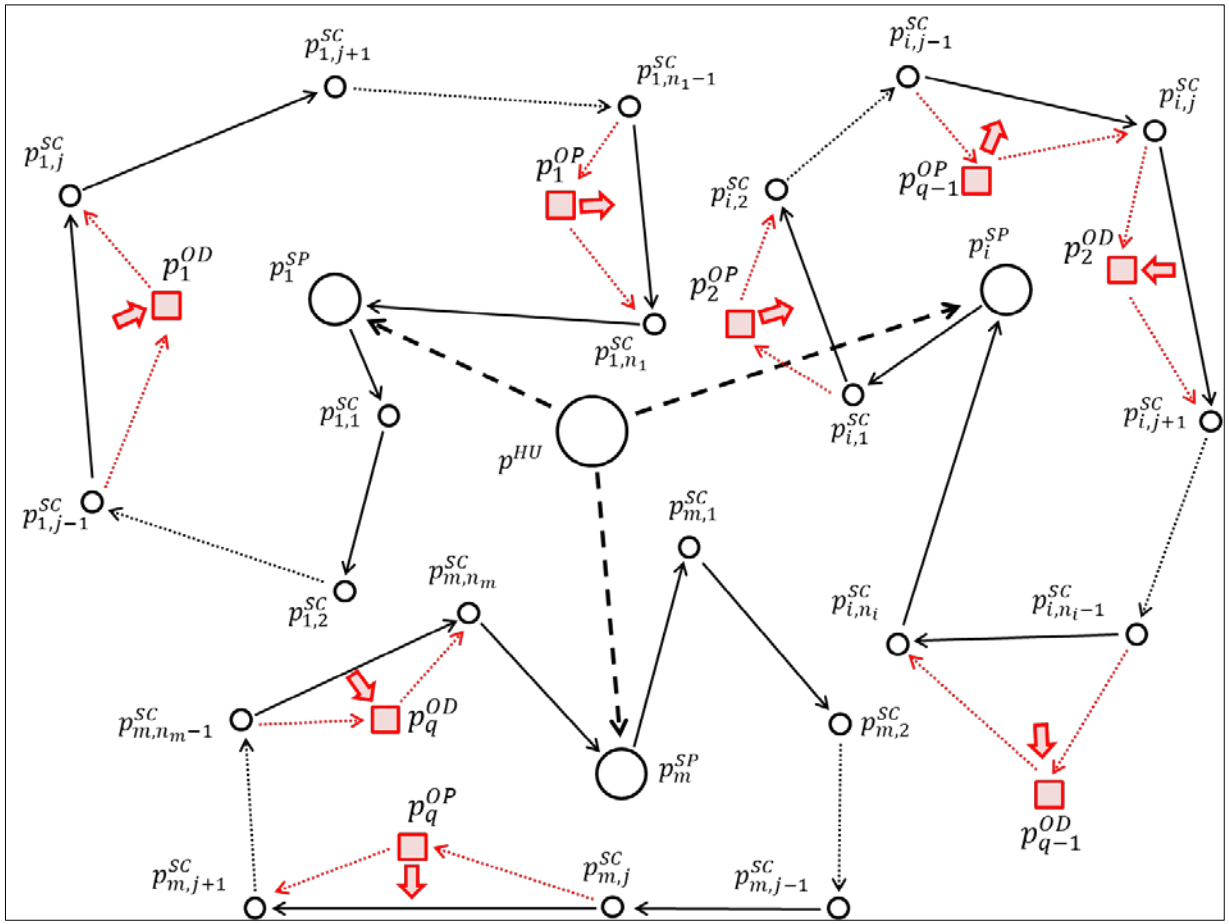
987 s

1039 s

Operation time [s]	ACI	ACO	AL	AU	ML	MU	MCI	MCO
Scenario 1	66	60	63	54	54	62	28	32
Scenario 2	0	0	63	54	54	62	0	0
Scenario 3	66	60	63	54	54	62	28	32

Operation time [s]	WCU	WCCO	WFL	WFCI	BWLU	BWCICO
Scenario 1	40	0	50	0	45	30
Scenario 2	40	78	50	56	45	30
Scenario 3	40	0	50	0	45	30

Model framework of dynamic milkrun scheduling



The decision variables:

- assignment of open tasks to scheduled routes,
- assignment of picked up packages to delivery routes ,
- scheduling of pickup operations of new tasks.

Objective function of the dynamic milkrun scheduling

transportation costs of scheduled delivery routes without assignment of open tasks

$$C^S = \sum_{i=1}^{m} \sum_{j=1}^{n_i-1} c_i(q_{i,j}) \cdot l_{i,j}(p_{i,j}^{SC})$$

costs of loading and traveling from the hub or spoke to the first destination

$$C^{SF} = \sum_{i=1}^{m} c_i(q_{i,j}) \cdot l_{i0}$$

costs of traveling from the last destination to the hub including unloading

$$C^{ST} = \sum_{i=1}^{m} c_i(q_{i,j}) \cdot l_{i,n_m}$$

$$\min C = C^S + C^{SF} + C^{ST} + C^{OP} + C^{OD}$$

$$C^{OP} = \sum_{k=1}^{q} \sum_{i=1}^{m} \sum_{j=1}^{n_i+\beta_i} x_{k,i,j} \cdot (l_{i,j,k} + l_{i,k,j+1}) \cdot c_i(q_{i,j})$$

the pickup costs of assigned open tasks

$$C^{OD} = \sum_{k=1}^{q} \sum_{i=1}^{m} \sum_{j=1}^{n_i+\beta_i} x_{k,i,j}^{*} \cdot (l_{i,j,k} + l_{i,k,j+1}) \cdot c_i(q_{i,j})$$

delivery costs of assigned open tasks

Constraints of dynamic milkrun scheduling

Constraints 1: The capacity of milkruns is not to exceed after assignment of open tasks.

$$q_{i,j} + \sum_{k=1}^{q} q_k \cdot x_{k,i,j} - \sum_{k=1}^{q} q_k \cdot x^*_{k,i,j+1} \leq Q_i^{max} \quad \forall i,j$$

Constraints 2: It is not allowed to exceed the upper and lower limit of pickup and delivery operation time in each scheduled destination within the time frame.

$$\tau_{i,j}^{min} \leq \tau_{i,j}^{s} + \sum_{k=1}^{q} x_{k,i,j} \cdot (\tau_{i,j,k}^{ao} + \tau_{i,k,j+1}^{ao}) \leq \tau_{i,j}^{max}$$

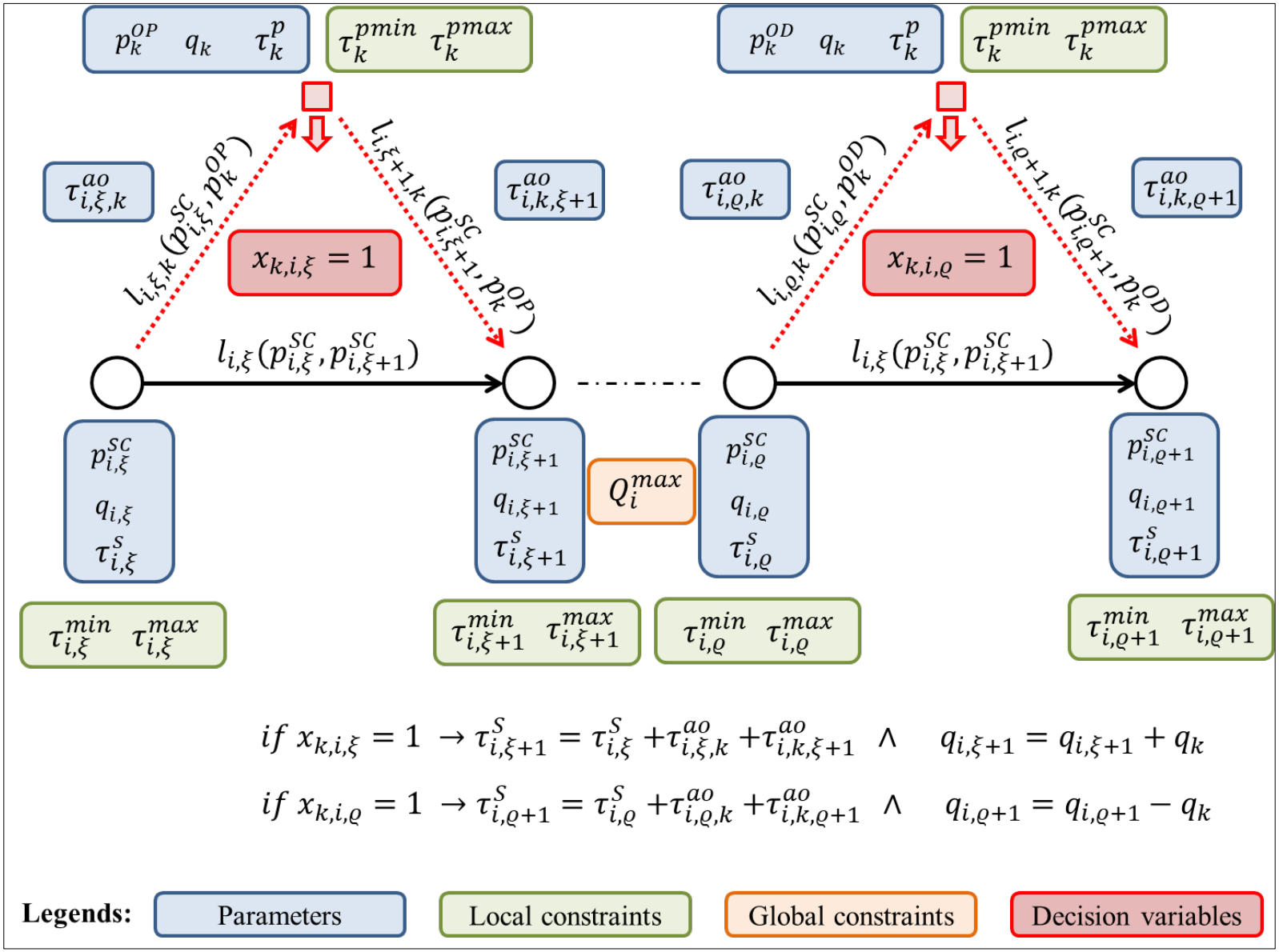
Constraints 3: It is not allowed to exceed the upper and lower limit of pickup operation time in each assigned open task destination within the time frame.

$$\tau_{k}^{pmin} \leq \tau_{i,j}^{s} + \sum_{k=1}^{q} x_{k,i,j} \cdot (\tau_{i,j,k}^{ao} + \tau_{i,k,j+1}^{ao}) \leq \tau_{k}^{pmax}$$

Constraints 4: It is not allowed to exceed the upper and lower limit of delivery time in each assigned open task destination within the time frame.

$$\tau_{k}^{dmin} \leq \tau_{i,j}^{s} + \sum_{k=1}^{q} x_{k,i,j} \cdot (\tau_{i,j,k}^{ao} + \tau_{i,k,j+1}^{ao}) \leq \tau_{k}^{dmax}$$

Constraints of dynamic milkrun scheduling



$$if\ x_{k,i,\xi} = 1 \rightarrow \tau_{i,\xi+1}^{S} = \tau_{i,\xi}^{S} + \tau_{i,\xi,k}^{ao} + \tau_{i,k,\xi+1}^{ao} \ \wedge \quad q_{i,\xi+1} = q_{i,\xi+1} + q_k$$

$$if\ x_{k,i,\varrho} = 1 \rightarrow \tau_{i,\varrho+1}^{S} = \tau_{i,\varrho}^{S} + \tau_{i,\varrho,k}^{ao} + \tau_{i,k,\varrho+1}^{ao} \ \wedge \quad q_{i,\varrho+1} = q_{i,\varrho+1} - q_k$$

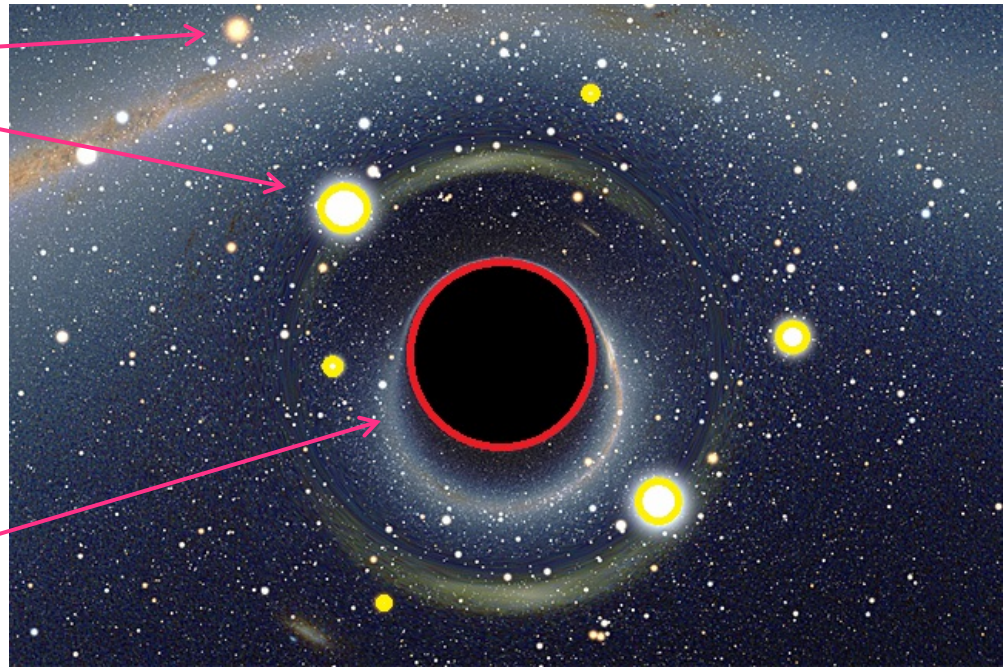
Legends: Parameters | Local constraints | Global constraints | Decision variables

Black Hole Algorithm

$$\vec{x}^{S_i} = \left(x_1^{S_i}, x_2^{S_i} \dots x_n^{S_i}\right) \; x_j^{S_i} \in \mathbb{N}$$

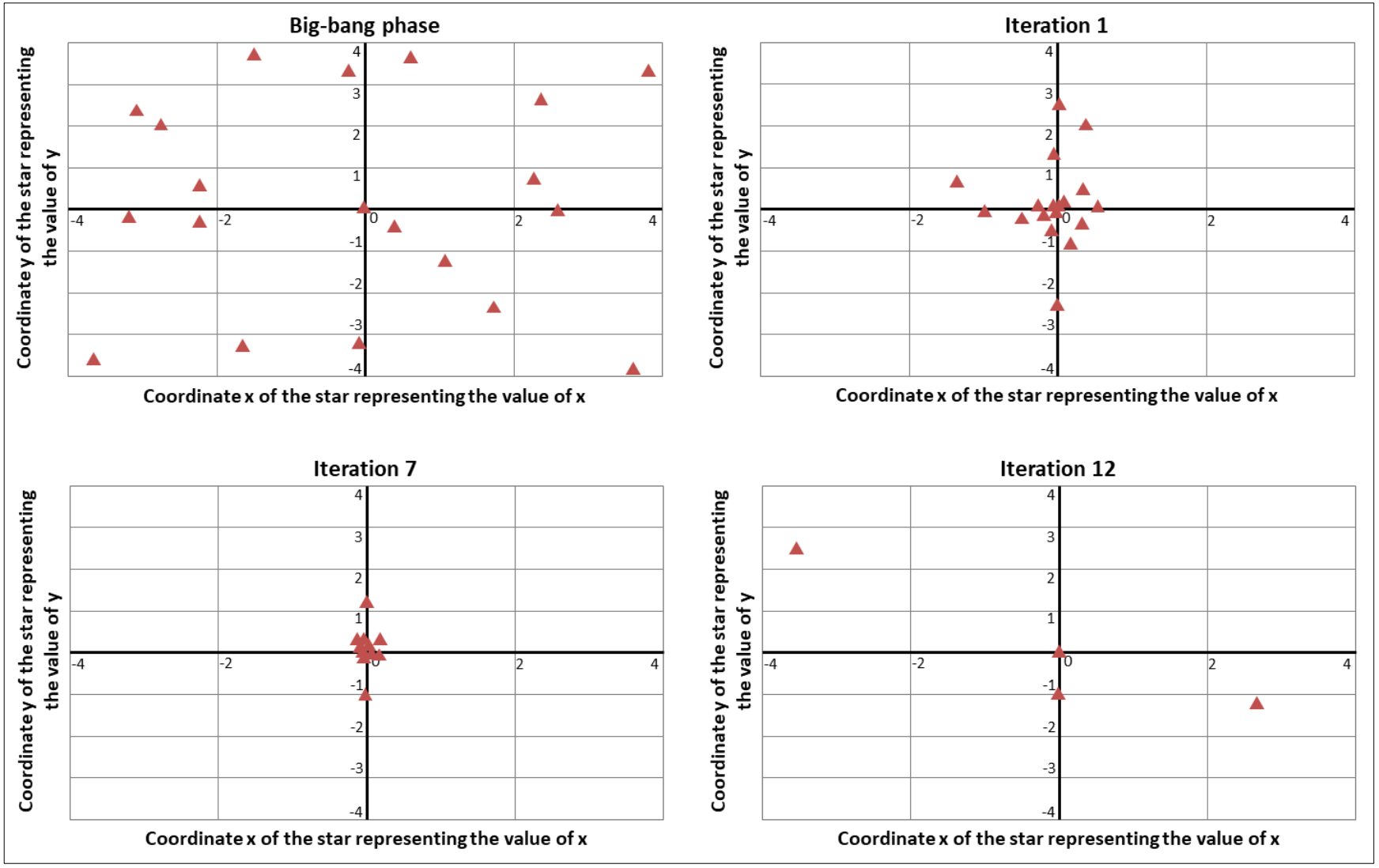
$$\mathrm{v}^{S_i} = \mathrm{v}^{S_i}\left(x_1^{S_i}, x_2^{S_i} \dots x_n^{S_i}\right)$$

$$\mathrm{v}^{BH} = \max_i(v^{S_i})$$

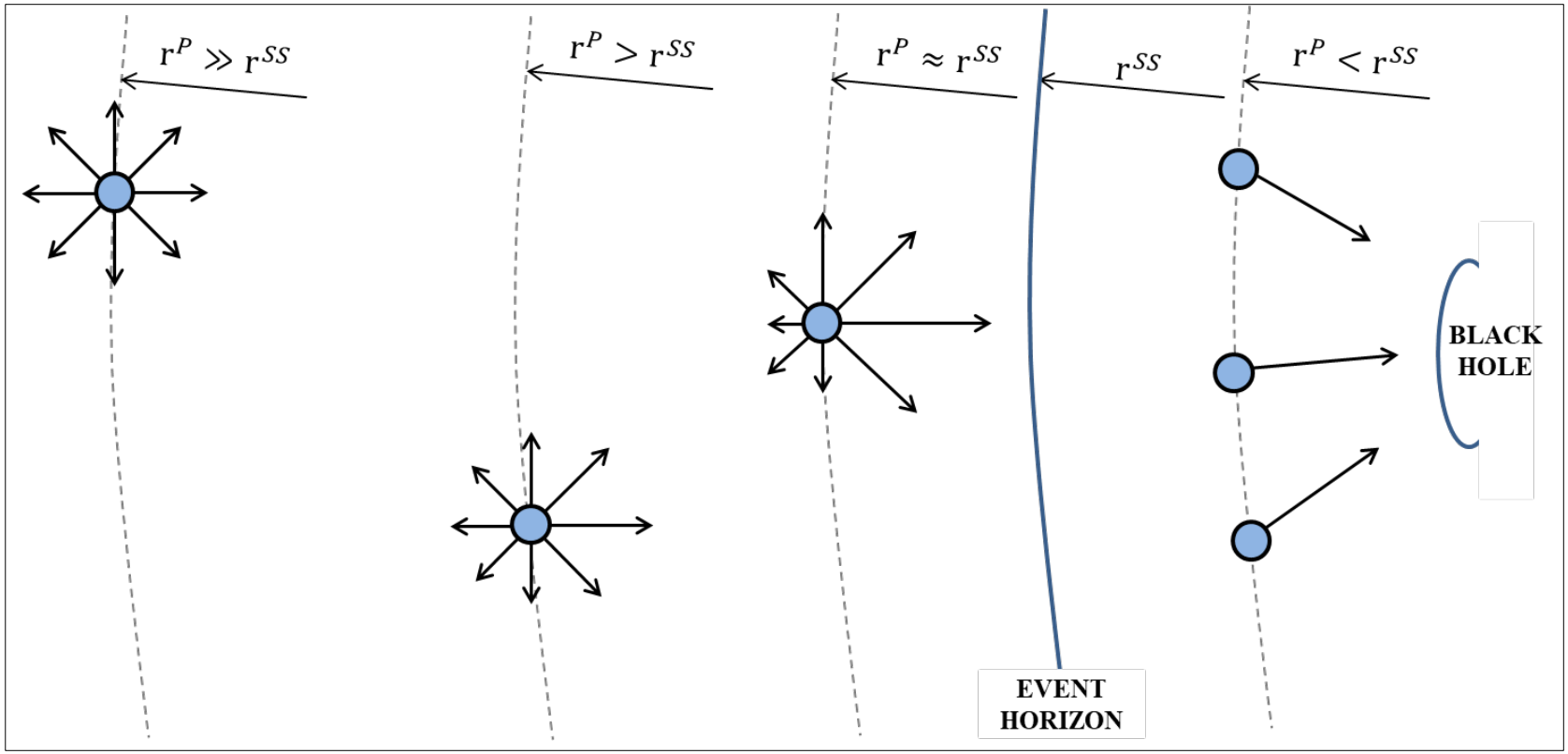


$$\mathrm{x}_j^{S_i}(t + \Delta t) = \mathrm{x}_j^{S_i}(t) + Round\left\{Rnd \cdot \left(\mathrm{x}_j^{BH}(t) - \mathrm{x}_j^{S_i}(t)\right)\right\}$$

Black Hole Algorithm



Impact of the distance between particles and event horizon (Schwarzschild radius) on the behavior of particles



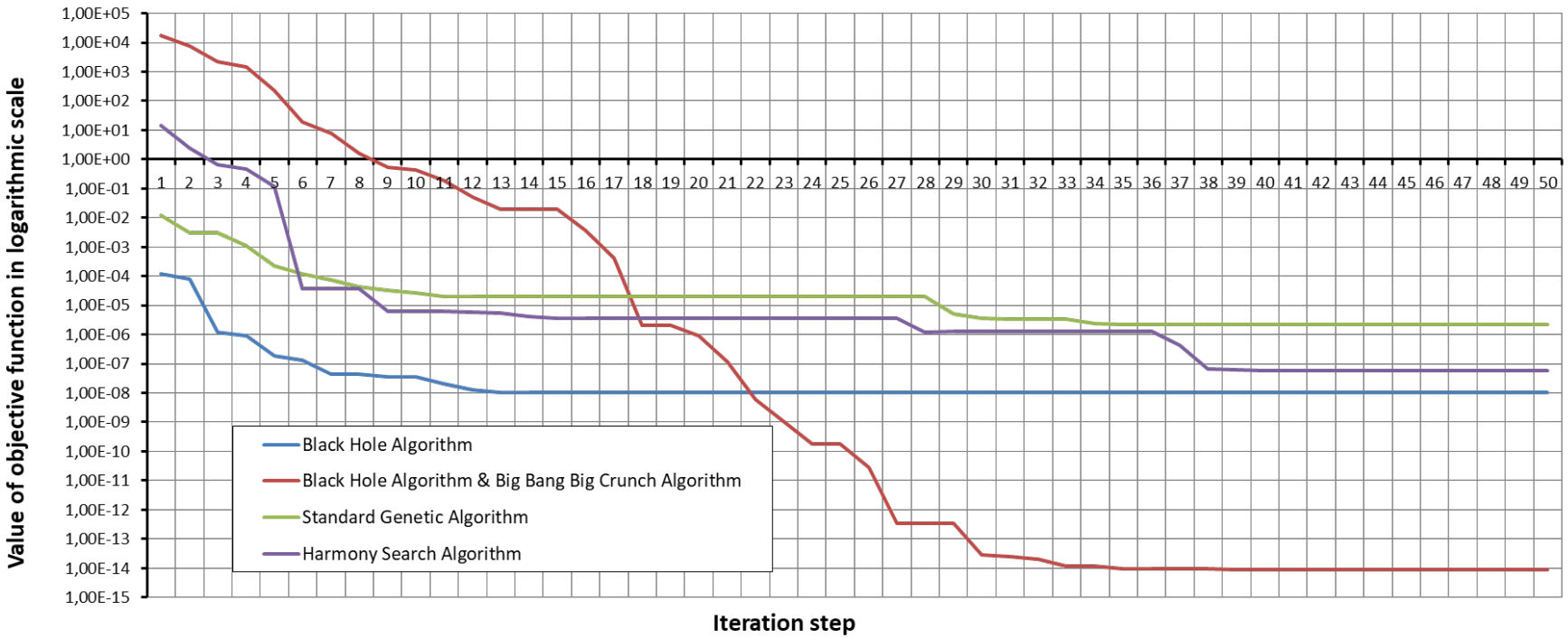
$$r^{SS} = \frac{f^{BH}}{\sum_{i=1}^{n} f^{S_i}}$$

$$x_j^{S_i} = x_j^{BH} + Round\left(\theta \cdot N(0,1) \cdot \frac{x_j^{S_i,max} - x_j^{S_i,min}}{\varepsilon}\right)$$

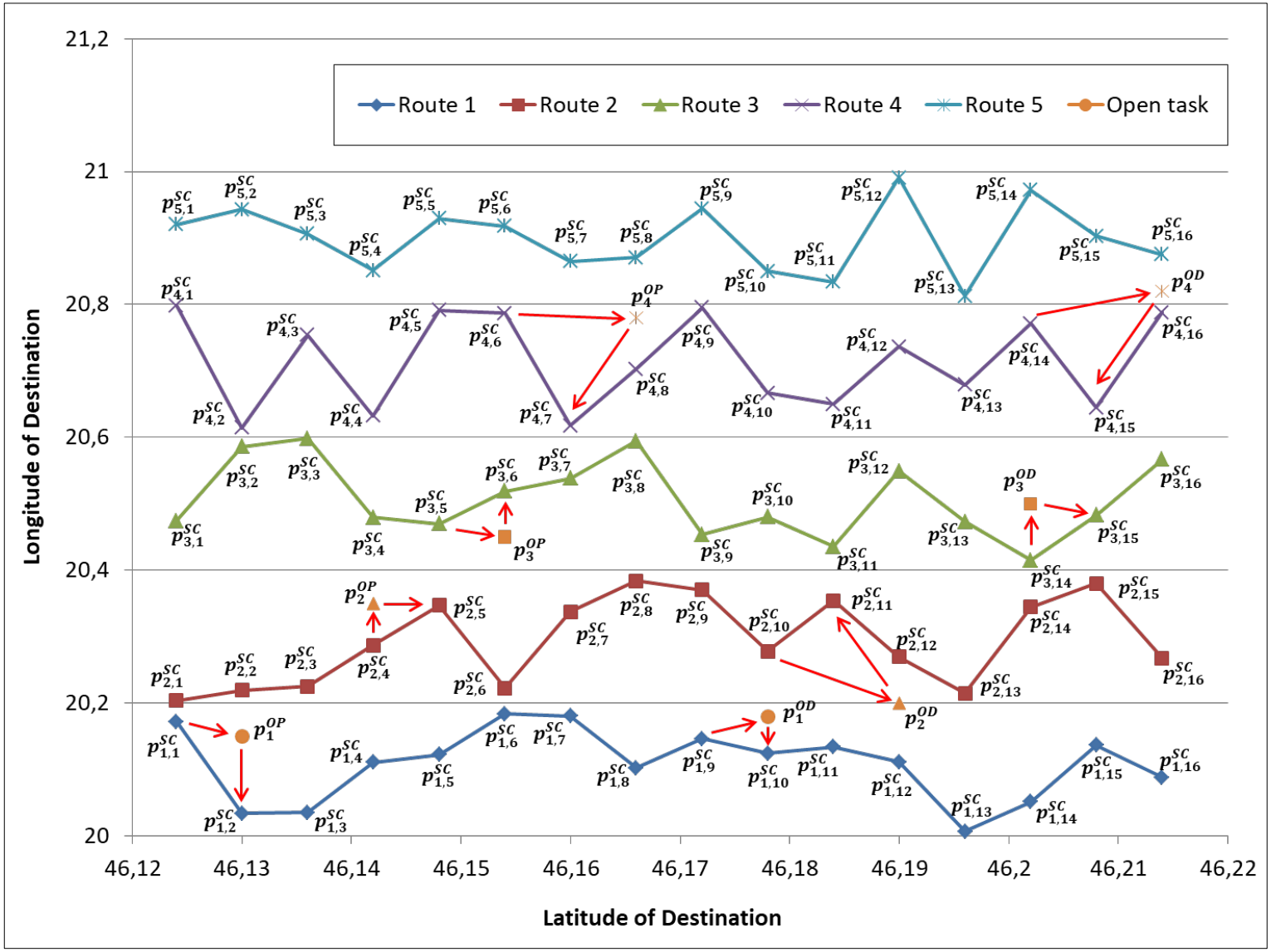
Error values of BHO in the case of 10 benchmark functions after 50 iteration steps

Evaluation function	Standard BHO	BHO & BBBC	Genetic Algorithm	Harmony Search
Ackley	3.66E-07	4.05E-11	4.67E-06	1.28E-07
Bukin	2.45E-06	3.58E-12	5.45E-07	9.08E-07
Cross-in-tray	8.55E-09	9.24E-11	7.32E-09	6.98E-08
Easom	1.18E-05	1.05E-10	2.09E-04	8.18E-09
Eggholder	5.50E-07	8.88E-14	3.12E-07	1.98E-08
Himmelblau	5.79E-08	9.14E-15	2.25E-06	1.05E-08
Lévi	1.20E-06	7.46E-09	7.34E-08	3.12E-08
Matyas	9.12E-08	7.59E-11	1.78E-07	6.70E-09
Modified sphere	2.21E-08	4.22E-10	1.93E-06	2.40E-08
Three hump camel	1.51E-06	8.06E-13	4.17E-08	7.79E-010

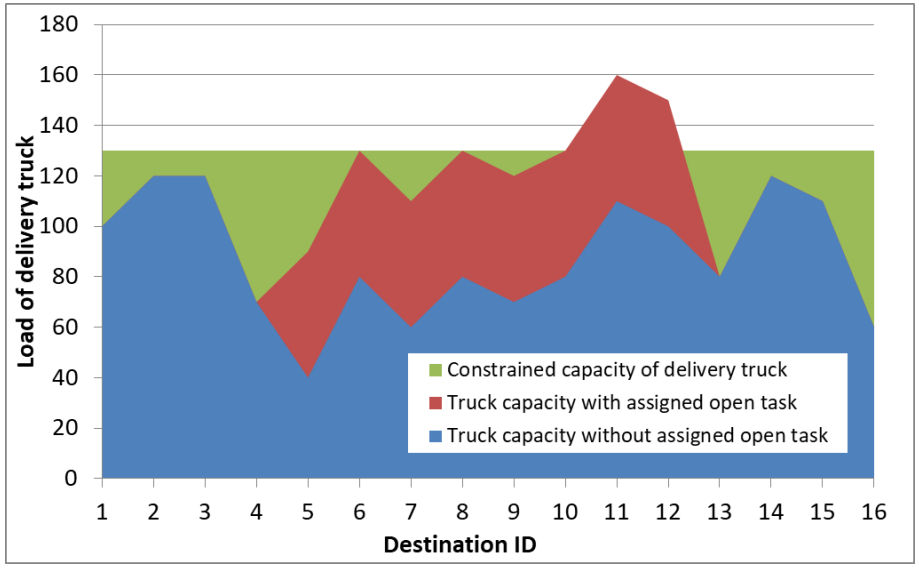
Convergence of algorithms in the case of Himmelblau's function

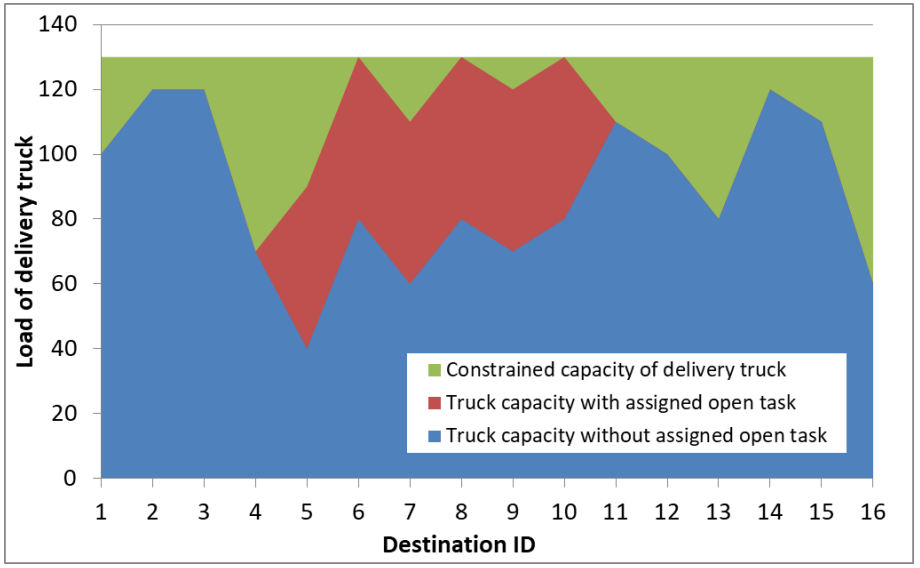


Scenario 1


Route 1
Route 2
Route 3
Route 4
Route 5
Open task
Longitude of Destination
Latitude of Destination
21,2
21
20,8
20,6
20,4
20,2
20
46,12
46,13
46,14
46,15
46,16
46,17
46,18
46,19
46,2
46,21
46,22

The load of delivery truck depending on the assigned pickup and delivery destination





Videos

- BMW Smart Transport: https://www.youtube.com/watch?v=Wan_M1PwcOQ
- Nipper: https://www.youtube.com/watch?v=uvsvrf-eB4g
- Dynamic milkrun: https://www.youtube.com/watch?v=S_x02BX71X4
- Still Liftrunner: https://www.youtube.com/watch?v=4mAVdAJPTu8

Thank you for your kind attention!