

**An agent-based Flexible Manufacturing System controller
with Petri-net enabled algebraic deadlock avoidance**

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1. Computation of Minimal Siphons in PIPE2 software tool

S1:P1, P10, P11, P14, P15, P17, P19, P22, P23, P26, P27, P29, P3, P31, P33, P35, P37, P39, P41, P43, P46, P47, P5, P50, P51, P54, P55, P58, P59, P62, P63, P66, P7, P67, P69, P71, P73, P75, ROBOT

S2:MACHINE_1, P11, P14, P15, P17, P19, P23, P26, P27, P3, P31, P33, P35, P37, P39, P43, P47, P5, P50, P51, P54, P58, P59, P62, P66, P7, P67, P71, P73, P75, ROBOT

S3:BUFFER_2, P16, P21, P32, P4, P45, P52, P60, P72, P9

S4:MACHINE_2, P13, P18, P25, P34, P38, P49, P56, P6, P64, P74}

S5:BUFFER_1, P20, P28, P40, P44, P53, P61, P68, P8

S6 :P36, P37, P38, P39, P40, P41, P42, P43, P44, P45, P46, P47, P48, P49, P50, P51, P52, P53, P54, P55, P56, P57, P58, P59, P60, P61, P62, P63, P64, P65, P66, P67, P68, P69, P70, P71, P72, P73, P74, P75

S7:MACHINE_1, MACHINE_2, P14, P15, P19, P26, P27, P3, P31, P35, P39, P43, P50, P51, P58, P59, P66, P7, P67, P71, P75, ROBOT

S8:MACHINE_1, P12, P2, P24, P30, P42, P48, P57, P65, P70

S9:BUFFER_2, MACHINE_1, MACHINE_2, P14, P19, P26, P27, P3, P35, P39, P43, P51, P59, P66, P7, P67, P75, ROBOT

S10:BUFFER_1, BUFFER_2, MACHINE_1, MACHINE_2, P14, P27, P3, P35, P39, P43, P51, P7, P67, P75, ROBOT

S11:BUFFER_1, MACHINE_1, MACHINE_2, P14, P15, P19, P27, P3, P31, P35, P39, P43, P50, P51, P58, P7, P67, P71, P75, ROBOT

S12:BUFFER_2, MACHINE_1, P11, P14, P17, P19, P23, P26, P27, P3, P33, P35, P37, P39, P43, P47, P5, P51, P54, P59, P62, P66, P7, P67, P73, P75, ROBOT

S13:BUFFER_1, BUFFER_2, MACHINE_1, P11, P14, P17, P23, P27, P3, P33, P35, P37, P39, P43, P47, P5, P51, P54, P62, P7, P67, P73, P75, ROBOT

S14:BUFFER_1, MACHINE_1, P11, P14, P15, P17, P19, P23, P27, P3, P31, P33, P35, P37, P39, P43, P47, P5, P50, P51, P54, P58, P62, P7, P67, P71, P73, P75, ROBOT

S15:MACHINE_2, P1, P10, P14, P15, P19, P22, P26, P27, P29, P3, P31, P35, P39, P41, P43, P46, P50, P51, P55, P58, P59, P63, P66, P7, P67, P69, P71, P75, ROBOT

S16:BUFFER_2, MACHINE_2, P1, P10, P14, P19, P22, P26, P27, P29, P3, P35, P39, P41, P43, P46, P51, P55, P59, P63, P66, P7, P67, P69, P75, ROBOT

S17:BUFFER_1, BUFFER_2, MACHINE_2, P1, P10, P14, P22, P27, P29, P3, P35, P39, P41, P43, P46, P51, P55, P63, P7, P67, P69, P75, ROBOT

S18:BUFFER_1, MACHINE_2, P1, P10, P14, P15, P19, P22, P27, P29, P3, P31, P35, P39, P41, P43, P46, P50, P51, P55, P58, P63, P7, P67, P69, P71, P75, ROBOT

S19:BUFFER_2, P1, P10, P11, P14, P17, P19, P22, P23, P26, P27, P29, P3, P33, P35, P37, P39, P41, P43, P46, P47, P5, P51, P54, P55, P59, P62, P63, P66, P7, P67, P69, P73, P75, ROBOT

S20:BUFFER_1, BUFFER_2, P1, P10, P11, P14, P17, P22, P23, P27, P29, P3, P33, P35, P37, P39, P41, P43, P46, P47, P5, P51, P54, P55, P62, P63, P7, P67, P69, P73, P75, ROBOT

S21:BUFFER_2, P0, P1, P10, P11, P12, P14, P16, P17, P2, P21, P23, P25, P27, P3, P32, P33, P34, P35, P4, P45, P5, P52, P6, P60, P7, P72, P8, P9

S22:BUFFER_2, P0, P1, P10, P11, P12, P14, P16, P17, P18, P19, P2, P20, P21, P22, P23, P25, P27, P3, P32, P33, P34, P35, P4, P45, P5, P52, P6, P60, P7, P72, P8, P9

S23:BUFFER_2, P0, P1, P10, P11, P12, P14, P16, P17, P18, P19, P2, P20, P21, P22, P23, P24, P25, P26, P27, P28, P29, P3, P32, P33, P34, P35, P36, P37, P38, P39, P4, P40, P41, P42, P43, P44, P45, P46, P47, P49, P5, P51, P52, P53, P54, P55, P6, P57, P59, P60, P61, P62, P63, P65, P7, P67, P72, P73, P74, P75, P8, P9

S24:BUFFER_2, P0, P1, P10, P11, P12, P13, P14, P15, P16, P17, P2, P21, P23, P25, P27, P3, P32, P33, P34, P35, P4, P45, P5, P52, P6, P60, P7, P72, P8, P9

S25:BUFFER_1, P1, P10, P11, P14, P15, P17, P19, P22, P23, P27, P29, P3, P31, P33, P35, P37, P39, P41, P43, P46, P47, P5, P50, P51, P54, P55, P58, P62, P63, P7, P67, P69, P71, P73, P75, ROBOT

S26:BUFFER_2, P0, P1, P10, P11, P12, P13, P14, P15, P16, P17, P18, P19, P2, P20, P21, P22, P23, P24, P25, P26, P27, P28, P29, P3, P32, P33, P34, P35, P36, P37, P38, P39, P4, P40, P41, P42, P43, P44, P45, P46, P47, P49, P5, P51, P52, P53, P54, P55, P6, P57, P59, P60, P61, P62, P63, P65, P7, P67, P72, P73, P74, P75, P8, P9

S27:P0, P1, P10, P11, P12, P13, P14, P15, P16, P17, P18, P19, P2, P20, P21, P22, P23, P24, P25, P26, P27, P28, P29, P3, P30, P31, P32, P33, P34, P35, P4, P5, P6, P7, P8, P9

S28:BUFFER_2, P0, P1, P10, P11, P12, P13, P14, P15, P16, P17, P18, P19, P2, P20, P21, P22, P23, P24, P25, P26, P27, P28, P29, P3, P30, P31, P32, P33, P34, P35, P36, P37, P38, P39, P4, P40, P41, P42, P43, P44, P45, P46, P47, P49, P5, P51, P52, P53, P54, P55, P6, P57, P59, P60, P61, P62, P63, P65, P7, P67, P72, P73, P74, P75, P8, P9

S29:BUFFER_2, P0, P1, P10, P11, P12, P13, P14, P15, P16, P17, P18, P19, P2, P20, P21, P22, P23, P24, P25, P26, P27, P28, P29, P3, P30, P31, P32, P33, P34, P35, P36, P37, P38, P39, P4, P40, P41, P42, P43, P44, P45, P46, P47, P48, P49, P5, P50, P51, P52, P53, P54, P55, P6, P57, P59, P60, P61, P62, P63, P65, P7, P67, P72, P73, P74, P75, P8, P9

2. Computation of T-vectors of the Strict Minimal Siphons of (1.)

$$\eta_{S_2} = -t_0 + t_2 - t_9 + t_{13} - t_{22} + t_{26} - t_{30} + t_{32} - t_{46} + t_{48} - t_{51} + t_{55} - t_{60} + t_{64} - t_{68} + t_{72} - t_{75} + t_{77}$$

$$\eta_{S_7} = -t_0 + t_2 - t_4 + t_6 - t_9 - t_{10} + t_{13} + t_{14} - t_{17} + t_{19} - t_{22} - t_{23} + t_{26} + t_{27} - t_{30} + t_{32} - t_{34} + t_{36} - t_{42}$$

$$+ t_{44} - t_{46} + t_{48} - t_{51} - t_{52} + t_{55} + t_{56} - t_{59} - t_{60} + t_{63} + t_{64} - t_{67} - t_{68} + t_{71} + t_{72} + t_{75} + t_{77} - t_{79} + t_{81}$$

$$\eta_{S_9} = -t_0 + t_2 - t_3 + t_6 - t_8 - t_9 + t_{13} - t_{15} - t_{17} + t_{19} - t_{21} - t_{22} + t_{26} + t_{27} - t_{30} + t_{36} - t_{42} + t_{44} - t_{46} + t_{48} - t_{50} - t_{51} + t_{55} + t_{56} - t_{60} + t_{63} + t_{64} - t_{68} + t_{71} + t_{72} - t_{75} + t_{81}$$

$$\eta_{S_{10}} = -t_0 + t_2 - t_3 + t_6 - t_7 - t_8 + t_{13} - t_{15} + t_{27} - t_{29} + t_{36} - t_{42} + t_{44} - t_{45} + t_{48} - t_{49} - t_{50} + t_{56} - t_{58} + t_{72} + t_{81}$$

$$\eta_{S_{11}} = -t_0 + t_2 - t_4 + t_6 - t_7 - t_{10} + t_{13} + t_{14} - t_{17} + t_{19} - t_{20} - t_{23} + t_{27} - t_{29} + t_{32} - t_{34} - t_{42} + t_{44} + -t_{45} + t_{48} - t_{49} - t_{52} + t_{55} + t_{56} - t_{58} - t_{59} + t_{63} - t_{67} + t_{72} + t_{77} - t_{79} + t_{81}$$

$$\eta_{S_{12}} = -t_0 + t_2 - t_3 + t_4 - t_8 - t_9 + t_{10} + t_{13} - t_{14} - t_{15} + t_{17} - t_{21} - t_{22} + t_{23} + t_{26} - t_{30} + t_{34} - t_{46} + t_{48} - t_{50} - t_{51} + t_{52} + t_{59} - t_{60} - t_{63} + t_{64} + t_{67} - t_{68} + t_{72} - t_{75} + t_{79}$$

$$\eta_{S_{13}} = -t_0 + t_2 - t_3 + t_4 - t_7 - t_8 + t_{10} + t_{13} - t_{14} - t_{15} + t_{17} - t_{19} + t_{23} - t_{29} + t_{34} - t_{45} + t_{48} - t_{49} - t_{50} + t_{52} - t_{58} + t_{59} - t_{63} + t_{67} - t_{68} - t_{71} + t_{72} + t_{79}$$

$$\eta_{S_{14}} = -t_0 + t_2 - t_7 + t_{13} - t_{20} - t_{29} + t_{32} - t_{45} + t_{48} - t_{49} + t_{55} - t_{58} - t_{71} - t_{72} + t_{77}$$

$$\eta_{S_{15}} = -t_4 + t_6 - t_{10} + t_{14} - t_{17} + t_{19} - t_{23} + t_{27} - t_{34} + t_{36} - t_{42} + t_{44} - t_{52} + t_{56} - t_{59} + t_{63} - t_{67} + t_{71} - t_{79} + t_{81}$$

$$\eta_{S_{16}} = -t_3 + t_6 - t_8 - t_{15} + t_{19} - t_{21} + t_{27} - t_{32} + t_{36} - t_{42} + t_{44} - t_{50} - t_{55} + t_{56} + t_{71} - t_{77} + t_{81}$$

$$\eta_{S_{17}} = -t_3 + t_6 - t_7 - t_8 + t_9 - t_{15} + t_{22} - t_{26} + t_{27} - t_{29} + t_{30} - t_{32} + t_{36} - t_{42} + t_{44} - t_{45} + t_{46} - t_{49}$$

$$- t_{50} + t_{51} - t_{55} + t_{56} - t_{58} + t_{60} - t_{64} + t_{68} + t_{75} - t_{77} + t_{81}$$

$$\eta_{S_{18}} = -t_4 + t_6 - t_7 + t_9 - t_{10} + t_{14} - t_{17} + t_{19} - t_{20} + t_{22} - t_{23} - t_{26} + t_{27} - t_{29} + t_{30} - t_{34} + t_{36} + t_{44} - t_{45} + t_{46} - t_{49} + t_{51} - t_{52} + t_{56} - t_{58} - t_{59} + t_{60} + t_{63} - t_{64} - t_{67} + t_{68} + t_{75} - t_{79} + t_{81}$$

$$\eta_{S_{19}} = -t_3 + t_4 - t_8 + t_{10} - t_{14} - t_{15} + t_{17} - t_{21} + t_{23} - t_{32} + t_{34} - t_{50} + t_{52} - t_{55} + t_{59} - t_{63} + t_{67} - t_{77} + t_{79}$$

$$\eta_{S_{20}} = -t_3 + t_4 - t_7 - t_8 + t_9 + t_{10} - t_{14} - t_{15} + t_{17} - t_{19} + t_{22} + t_{23} - t_{29} + t_{30} - t_{32} + t_{34} - t_{45} + t_{46} - t_{49}$$

$$- t_{50} + t_{51} + t_{52} - t_{55} - t_{58} + t_{59} + t_{60} - t_{63} - t_{64} + t_{67} + t_{68} - t_{71} + t_{75} - t_{77} + t_{79}$$

$$\eta_{S_{21}} = -t_3 + t_4 - t_8 + t_{10} - t_{12} - t_{15} + t_{17} - t_{18} + t_{23} - t_{29} + t_{34}$$

$$\eta_{S_{22}} = -t_3 + t_4 - t_8 + t_{10} - t_{12} - t_{15} + t_{17} - t_{21} + t_{23} - t_{24} - t_{29} + t_{34}$$

$$\eta_{S_{23}} = -t_3 + t_4 - t_8 + t_{10} - t_{12} - t_{15} + t_{17} - t_{21} + t_{23} - t_{31} + t_{34} - t_{50} + t_{52} - t_{53} + t_{59} - t_{61} + t_{67} - t_{69} + t_{79}$$

$$\eta_{S_{24}} = -t_3 + t_4 - t_8 + t_{10} - t_{15} - t_{16} + t_{17} - t_{18} + t_{23} - t_{29} + t_{34}$$

$$\eta_{S_{25}} = -t_7 + t_9 - t_{20} + t_{22} - t_{26} - t_{29} + t_{30} - t_{45} + t_{46} - t_{49} + t_{51} - t_{58} + t_{60} - t_{64} + t_{68} - t_{71} + t_{75}$$

$$\eta_{S_{26}} = -t_3 + t_4 - t_8 + t_{10} - t_{15} - t_{16} + t_{17} - t_{21} + t_{23} - t_{31} + t_{34} - t_{50} + t_{52} - t_{53} + t_{59} - t_{61} + t_{67} - t_{69} + t_{79}$$

$$\eta_{S_{28}} = -t_3 + t_4 - t_8 + t_{10} - t_{15} - t_{16} + t_{17} - t_{21} + t_{23} - t_{33} + t_{34} - t_{50} + t_{52} - t_{53} + t_{59} - t_{61} + t_{67} - t_{69} + t_{79}$$

$$\eta_{S_{29}} = -t_3 + t_4 - t_8 + t_{10} - t_{15} - t_{16} + t_{17} - t_{21} + t_{23} - t_{33} + t_{34} - t_{50} + t_{52} - t_{57} + t_{59} - t_{61} + t_{67} - t_{69} + t_{79}$$

3. Computation of the complementary siphons of Strict Minimal siphons

For the complementary siphons' computation $[S_i]$, we initially recognize the places r indicating the resources of our system on S_i . Then, we continue with the computation of the holders $H(r)$ of the resources which equals to the difference of multi-sets I_r from their corresponding places r , $H(r) = I_r - r$. The complementary set $Th(S)$ is finally computed by the difference of the sum of holders, referring to the corresponding resources, from the rest of operation places included in S , formally $Th(S) = \sum_{r \in S^R} H(r) - \sum_{r \in S^R, p \in S^A} I_r(p)$.

$$[S_2] = [P_1, P_2, P_{10}, P_{12}, P_{22}, P_{24}, P_{29}, P_{30}, P_{41}, P_{42}, P_{46}, P_{48}, P_{55}, P_{57}, P_{63}, P_{65}, P_{69}, P_{70}]$$

$$[S_7] = [P_1, P_{10}, P_{11}, P_{12}, P_{13}, P_{17}, P_{18}, P_2, P_{22}, P_{23}, P_{24}, P_{25}, P_{29}, P_{30}, P_{33}, P_{34}, P_{35}, P_{37}, P_{38}, P_{41}, P_{42}, P_{46}, P_{47}, P_{48}, P_{49}, P_5, P_{54}, P_{55}, P_6, P_{56}, P_{57}, P_{62}, P_{63}, P_{64}, P_{65}, P_{70}, P_{73}, P_{74}]$$

$$[S_9] = [P_1, P_{10}, P_{11}, P_{12}, P_{13}, P_{15}, P_{16}, P_{17}, P_{18}, P_2, P_{21}, P_{22}, P_{23}, P_{24}, P_{25}, P_{29}, P_{30}, P_{31}, P_{32}, P_{33}, P_{34}, P_{37}, P_{38}, P_4, P_{41}, P_{42}, P_{45}, P_{46}, P_{47}, P_{48}, P_{49}, P_5, P_{50}, P_{52}, P_{54}, P_{55}, P_{56}, P_{57}, P_{58}, P_6, P_{60}, P_{62}, P_{63}, P_{64}, P_{65}, P_{69}, P_{70}, P_{71}, P_{72}, P_{73}, P_{74}, P_9]$$

$$[S_{10}] = [P_1, P_{10}, P_{11}, P_{12}, P_{13}, P_{15}, P_{16}, P_{17}, P_{18}, P_{19}, P_2, P_{20}, P_{21}, P_{22}, P_{23}, P_{24}, P_{26}, P_{28}, P_{29}, P_{30}, P_{31}, P_{32}, P_{33}, P_{34}, P_{37}, P_{38}, P_4, P_{40}, P_{41}, P_{42}, P_{43}, P_{45}, P_{46}, P_{47}, P_{48}, P_{49}, P_5, P_{50}, P_{52}, P_{53}, P_{54}, P_{55}, P_{56}, P_6, P_{57}, P_{59}, P_{60}, P_{61}, P_{62}, P_{63}, P_{64}, P_{65}, P_{66}, P_7, P_{68}, P_{69}, P_{70}, P_{71}, P_{72}, P_{73}, P_{74}, P_{75}, P_8, P_9]$$

$$[S_{11}] = [P_1, P_{10}, P_{11}, P_{12}, P_{13}, P_{17}, P_{18}, P_2, P_{20}, P_{22}, P_{23}, P_{24}, P_{25}, P_{26}, P_{28}, P_{29}, P_{30}, P_{33}, P_{34}, P_{37}, P_{38}, P_{40}, P_{41}, P_{42}, P_{43}, P_{46}, P_{47}, P_{49}, P_5, P_{53}, P_{54}, P_{55}, P_{56}, P_6, P_{57}, P_{59}, P_{61}, P_{62}, P_{63}, P_{64}, P_{65}, P_{66}, P_{68}, P_{69}, P_{70}, P_{73}, P_{74}, P_8]$$

$$[S_{21}] = [P_0, P_1, P_{10}, P_{11}, P_{12}, P_{14}, P_{17}, P_2, P_{23}, P_{25}, P_{27}, P_3, P_{33}, P_{34}, P_{35}, P_5, P_6, P_7, P_8]$$

$$[S_{22}] = [P_0, P_1, P_{10}, P_{11}, P_{12}, P_{14}, P_{17}, P_{18}, P_{19}, P_2, P_{20}, P_{22}, P_{23}, P_{25}, P_{27}, P_3, P_{33}, P_{34}, P_{35}, P_5, P_6, P_7, P_8]$$

$$[S_{23}] = [P_0, P_1, P_{10}, P_{11}, P_{12}, P_{14}, P_{17}, P_{18}, P_{19}, P_2, P_{20}, P_{22}, P_{23}, P_{24}, P_{25}, P_{26}, P_{27}, P_{28}, P_{29}, P_3, P_{33}, P_{34}, P_{35}, P_{36}, P_{37}, P_{38}, P_{39}, P_{40}, P_{41}, P_{42}, P_{43}, P_{44}, P_{46}, P_{47}, P_{49}, P_5, P_{51}, P_{53}, P_{54}, P_{55}, P_{57}, P_{59}, P_6, P_{61}, P_{62}, P_{63}, P_{65}, P_{67}, P_7, P_{73}, P_{74}, P_{75}, P_8]$$

$$[S_{24}] = [P_0, P_1, P_{10}, P_{11}, P_{12}, P_{13}, P_{14}, P_{15}, P_{17}, P_2, P_{23}, P_{25}, P_{27}, P_3, P_{33}, P_{34}, P_{35}, P_5, P_6, P_7, P_8]$$

$$[S_{28}] = [P_0, P_1, P_{10}, P_{11}, P_{12}, P_{13}, P_{15}, P_{16}, P_{17}, P_{18}, P_{19}, P_2, P_{20}, P_{22}, P_{23}, P_{24}, P_{25}, P_{26}, P_{27}, P_{28}, P_{29}, P_3, P_{30}, P_{31}, P_{33}, P_{34}, P_{35}, P_{36}, P_{37}, P_{38}, P_{39}, P_{40}, P_{41}, P_{42}, P_{43}, P_{44}, P_{46}, P_{47}, P_{49}, P_5, P_{51}, P_{53}, P_{54}, P_{55}, P_{57}, P_{59}, P_6, P_{61}, P_{62}, P_{63}, P_{65}, P_{67}, P_7, P_{73}, P_{74}, P_{75}, P_8]$$

$$[S_{29}] = [P_0, P_1, P_{10}, P_{11}, P_{12}, P_{13}, P_{15}, P_{16}, P_{17}, P_{18}, P_{19}, P_2, P_{20}, P_{22}, P_{23}, P_{24}, P_{25}, P_{26}, P_{27}, P_{28}, P_{29}, P_3, P_{30}, P_{31}, P_{33}, P_{34}, P_{35}, P_{36}, P_{37}, P_{38}, P_{39}, P_{40}, P_{41}, P_{42}, P_{43}, P_{44}, P_{46}, P_{47}, P_{48}, P_{49}, P_5, P_{50}, P_{51}, P_{53}, P_{54}, P_{55}, P_{57}, P_{59}, P_6, P_{61}, P_{62}, P_{63}, P_{65}, P_{67}, P_7, P_{73}, P_{74}, P_{75}, P_8]$$