Universidade Federal
do Rio de Janeiro
Escola Politécnica

IDENTIFICATION AND FAILURE DETECTION IN A DIDACTIC MANUFACTURE SYSTEM

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Projeto de Graduação apresentado ao Curso de Engenharia de Controle e Automação da Escola Politécnica, Universidade Federal do Rio de Janeiro, como parte dos requisitos necessários à obtenção do título de Engenheiro de Controle e Automação.

Orientador: Marcos Vicente de Brito Moreira

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Examinado por:

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1. Failure Detection. 2. Discrete Event Systems. I. Moreira, Marcos Vicente de Brito. II. Universidade Federal do Rio de Janeiro, Escola Politécnica, Curso de Engenharia de Controle e Automação. III. Identification and Failure Detection in a Didactic Manufacture System.

"It's a dangerous business going out your door. You step onto the road, and if you don't keep your feet, there's no knowing where you might be swept off to."
(J.R.R Tolkien)

Agradecimentos

Gostaria de agradecer primeiramente a Deus, pois sem Ele nada é possível e por **todas** as pessoas qu'Ele colocou em meu caminho, que me fizeram crescer e ser o indivíduo que hoje sou.

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Abstract of Undergraduate Project presented to POLI/UFRJ as a partial fulfillment of the requirements for the degree of Automation and Control Engineering.

IDENTIFICATION AND FAILURE DETECTION IN A DIDACTIC MANUFACTURE SYSTEM

Rafael Accácio Nogueira

April/2019

Advisor: Marcos Vicente de Brito Moreira

Course: Automation and Control Engineering

This work has as primary objective to propose tools and a methodology for identification and failure detection on discrete events systems using the Deterministic Automaton with Outputs and Conditional Transitions (DAOCT) model. In order to accomplish this, the control of a didactic manufacture system will be designed, using petri nets in a first phase converting it into Ladder. Once the control is implemented, it will be showed how to make the input and output data acquisition necessary to feed the DAOCT model identification algorithm. The DAOCT model identified by the offline program, using data acquired when the system was operational in normal conditions, will be used online to detect failures in tests where the failures will be created by fiddling around with the sensors and actuators, this way the model will be tested using relatively larger systems.

1. Failure Detection. 2. Discrete Event Systems.

Resumo do Projeto de Graduação apresentado à Escola Politécnica/ UFRJ como parte dos requisitos necessários para a obtenção do grau de Engenheiro de Controle e Automação.

IDENTIFICAÇÃO E DETECÇÃO DE FALHAS EM UM SISTEMA DE MANUFATURA DIDÁTICO

Rafael Accácio Nogueira

Abril/2019

Orientador: Marcos Vicente de Brito Moreira

Curso: Engenharia de Controle e Automação

Este trabalho tem como objetivo propor ferramentas e uma metodologia para a identificação e detecção de falhas em sistemas a eventos discretos, utilizando o modelo DAOCT. Para tanto, será realizado o projeto de controle de um sistema de manufatura didático, utilizando em uma primeira fase redes de petri, depois convertendo na linguagem Ladder. Uma vez implementado o controle será mostrado como fazer a aquisição dos dados de entrada e saída da planta, necessários para o algoritmo de identificação do modelo DAOCT. O modelo DAOCT identificado pelo programa offline, usando dados colhidos em diversos testes no qual a planta se comporta normalmente, será usado para detectar falhas online em testes onde situações de falhas serão causadas ao alterar o comportamento de sensores e atuadores, assim testando o modelo para sistemas de relativamente maiores dimensões

1. Failure Detection. 2. Discrete Event Systems.

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Examples

1.1 teste

1.1.1 teste

teste

Input: scalar ϵ, matrix $\mathbf{A} = (a_{ij})$, vector $\vec{b}$ and initial vector $\vec{x}^{(0)}$
for $k \leftarrow 1$ **to** *maximum iterations* **do**
    for $i \leftarrow 1$ **to** n **do**
        $x_i^{(k)} = \frac{b_i - \sum_{j=1}^{i-1} a_{ij} x_j^{(k)} - \sum_{j=i+1}^{n} a_{ij} x_j^{(k-1)}}{a_{ii}}$;
    end
    if $|\vec{x}^{(k)} - \vec{x}^{(k-1)}| < \epsilon$ **then**
        Stop
    end
end

Algorithm 1: Gauss-Seidel Algorithm

Ω

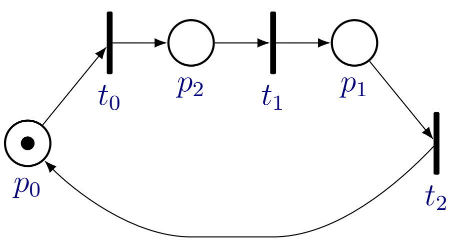

Figure 1.1: petri net example

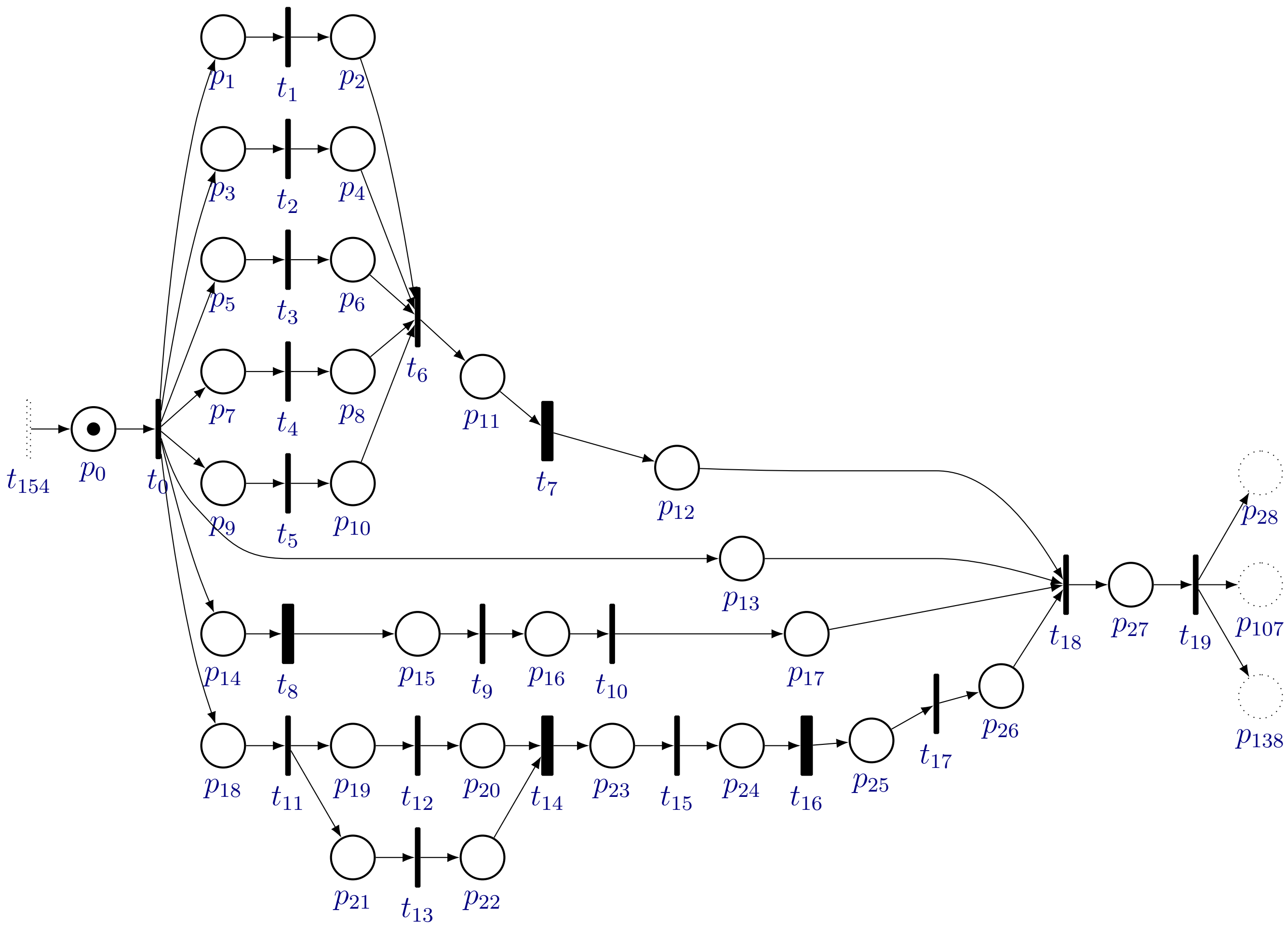

Figure 1.2: Petri net of Initialization module.

Table 1.1: Initialization Module Places.

Places	Meaning
p_0	System Stopped
p_1	Retract MAG1's Cylinder *
p_2	MAG1's Cylinder Retracted
p_3	Retract MAG2's Cylinder *
p_4	MAG2's Cylinder Retracted
p_5	Retract Right Discharge Cylinder *
p_6	Right Discharge Cylinder Retracted
p_7	Retract Center Discharge Cylinder
p_8	Center Discharge Cylinder Retracted
p_9	Retract Left Discharge Cylinder *
p_{10}	Left Discharge Cylinder Retracted
p_{11}	Turn Conveyor Belt On (Reverse)
p_{12}	No Pieces On Conveyor Belt
p_{13}	Reset Variables[1]
p_{14}	Raise Press
p_{15}	Open Safety Door
p_{16}	Extend Assembly Unit Holder
p_{17}	Assembly Unit Ready
p_{18}	Arm Lowered and Retracted, and Storage Unit Retracted
p_{19}	Move Storage Unit to the Right
p_{20}	Storage Unit ready (horizontal)
p_{21}	Move Storage Device Downwards
p_{22}	Storage Unit ready (vertical)
p_{23}	Rotate Arm CCW
p_{24}	Arm Stopped
p_{25}	Rotate Arm CW e Turn HSC ON
p_{26}	Arm Stopped (facing conveyor belt)
p_{27}	System Ready

[1] Counter Variables: HALFPIECECOUNTER, COUNTER1, COUNTER2, COUNTER3, COUNTER4, COUNTER5.

Table 1.2: Initialization Module Transitions.

Transitions	Meaning
t_0	Initialization Button
t_1	MAG1's Cylinder Retracted
t_2	MAG2's Cylinder Retracted
t_3	Right Discharge Cylinder Retracted
t_4	Center Discharge Cylinder Retracted
t_5	Left Discharge Cylinder Retracted
t_6	
t_7	T=15s
t_8	T=2.5s
t_9	Safety Door Opened
t_{10}	Assembly Unit Holder Extended
t_{11}	Storage Unit Retracted and Arm Lowered and Retracted
t_{12}	Storage Unit Right Limit Switch
t_{13}	Storage Unit Inferior Limit Switch
t_{14}	T=2s
t_{15}	Inductive Sensor Arm
t_{16}	T=1s
t_{17}	ARMCOUNTER = -1690
t_{18}	
t_{19}	Start Button

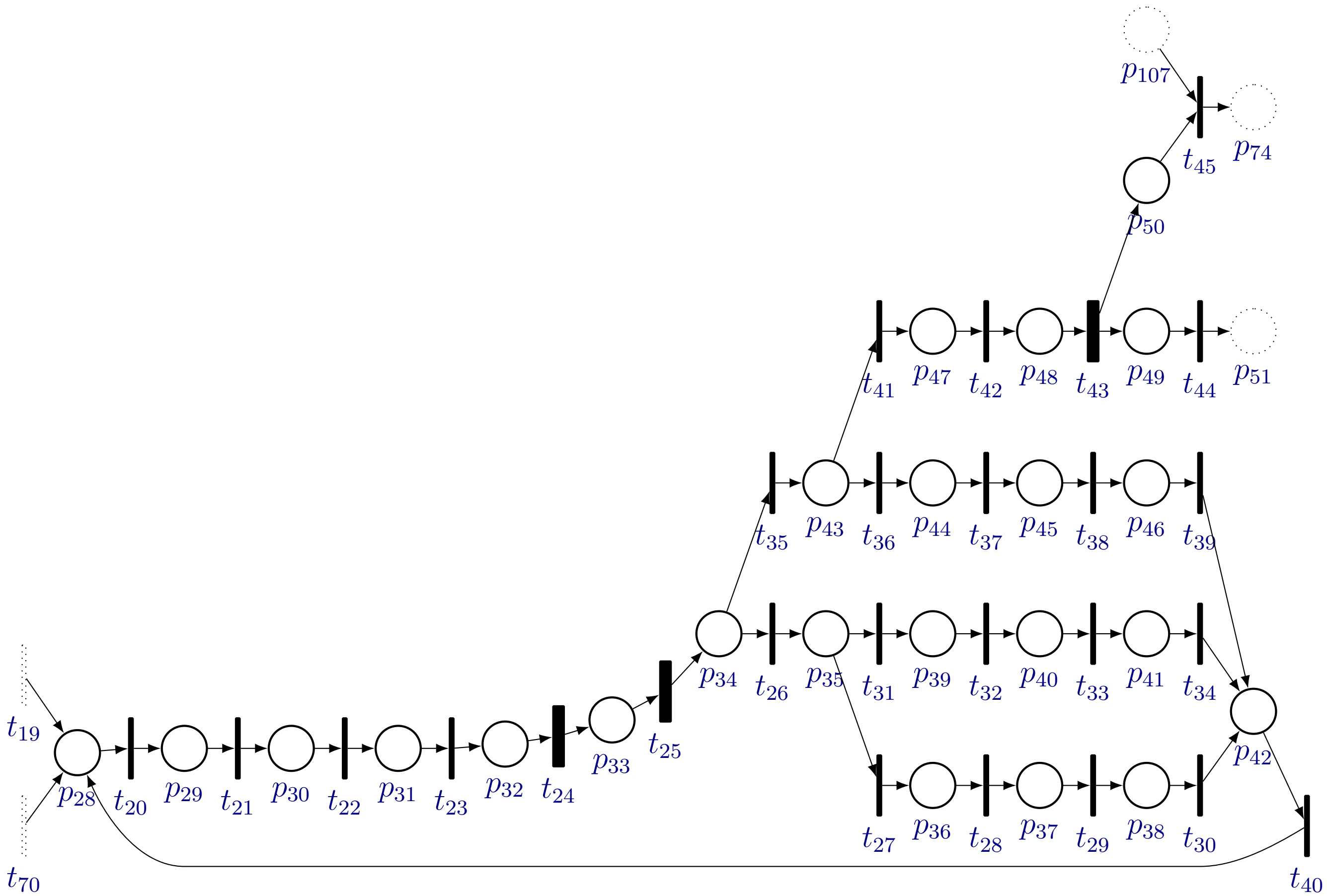

Figure 1.3: Petri net of metal cube half sorting module.

Table 1.3: Metal Half-cube Selection Module Places.

Places	Meaning
p_{28}	MAG1 Empty
p_{29}	MAG1 Not Empty
p_{30}	Extend MAG1's Cylinder *
p_{31}	Retract MAG1's Cylinder *
p_{32}	MAG1's Cylinder Retracted
p_{33}	Turn Conveyor Belt On
p_{34}	
p_{35}	Plastic Half-cube
p_{36}	Turn Conveyor Belt On
p_{37}	Extend Right Discharge Cylinder *
p_{38}	Retract Right Discharge Cylinder *
p_{39}	Turn Conveyor Belt On
p_{40}	Extend Center Discharge Cylinder *
p_{41}	Retract Center Discharge Cylinder *
p_{42}	
p_{43}	Metal Half-cube
p_{44}	Turn Conveyor Belt On
p_{45}	Extend Left Discharge Cylinder *
p_{46}	Retract Left Discharge Cylinder *
p_{47}	Turn Conveyor Belt On
p_{48}	Turn Conveyor Belt On
p_{49}	Metal Half-cube Ready
p_{50}	Conveyor Belt Stopped

Table 1.4: Metal Half-cube Selection Module Transitions.

Transitions	Meaning
t_{20}	$\overline{\text{MAG1 Empty}}$
t_{21}	
t_{22}	MAG1's Cylinder Extended $\uparrow$
t_{23}	MAG1's Cylinder Retracted $\uparrow$
t_{24}	T=0.5s
t_{25}	Presence $\uparrow$ T=0.5s
t_{26}	$\overline{\text{Metallic Sensor}}$
t_{27}	$\overline{\text{White Color Sensor}}$
t_{28}	Proximity Sensor Left Discharge Cylinder $\uparrow$
t_{29}	Right Discharge Cylinder Extended
t_{30}	Right Discharge Cylinder Retracted
t_{31}	White Color Sensor
t_{32}	Proximity Sensor Center Discharge Cylinder $\uparrow$
t_{33}	Center Discharge Cylinder Extended
t_{34}	Center Discharge Cylinder Retracted
t_{35}	Metallic Sensor
t_{36}	Concavity downwards
t_{37}	Proximity Sensor Left Discharge Cylinder $\uparrow$
t_{38}	Left Discharge Cylinder Extended
t_{39}	Left Discharge Cylinder Retracted
t_{40}	
t_{41}	Concavity downwards
t_{42}	Proximity Sensor End Of Conveyor Belt $\uparrow$
t_{43}	T=0.5s
t_{44}	Proximity Sensor End Of Conveyor Belt $\downarrow$
t_{45}	

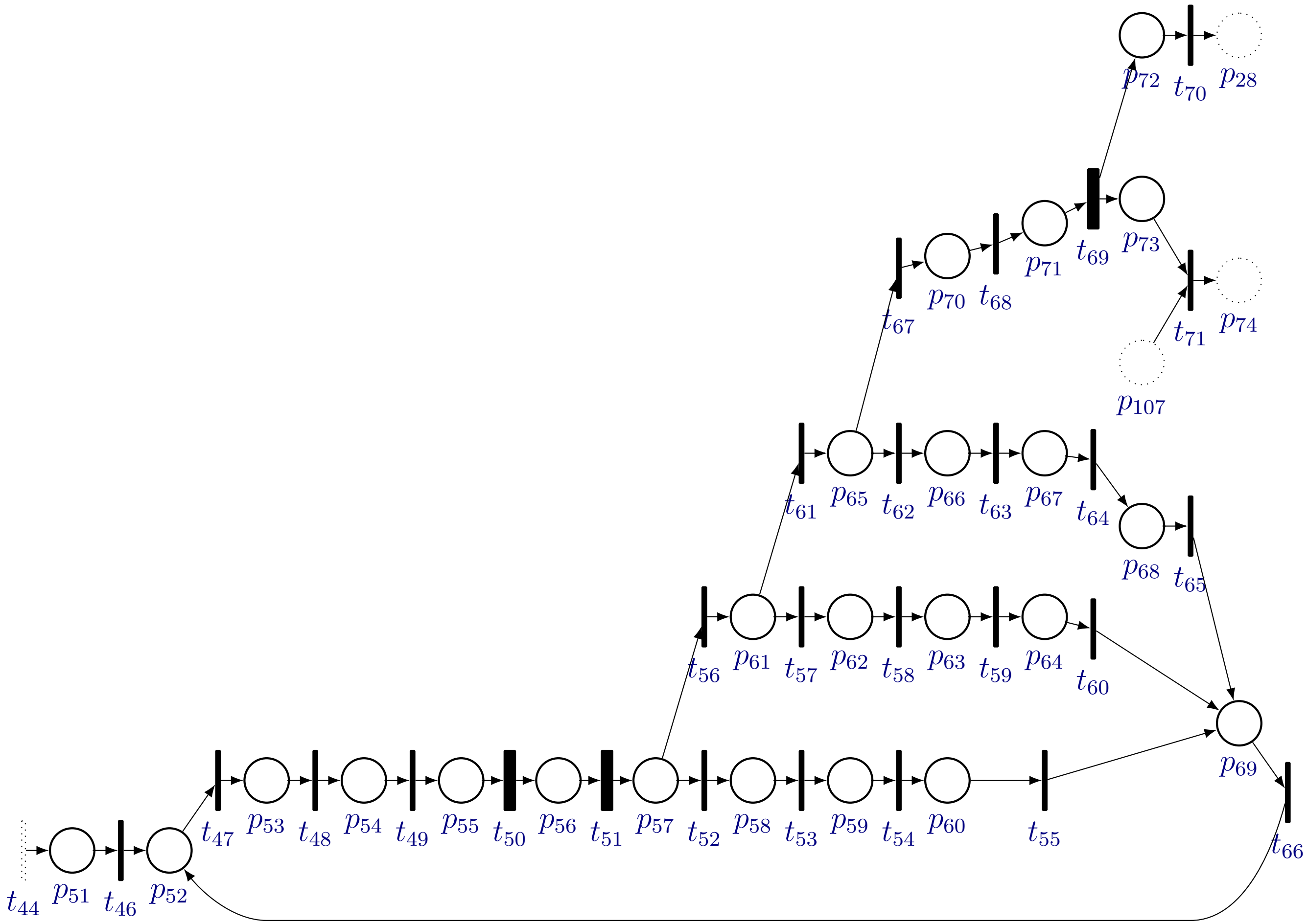

Figure 1.4: Petri net of plastic cube half sorting module.

Table 1.5: Plastic Half-cube Selection Module Places.

Places	Meaning
p_{51}	MAG2 Empty
p_{52}	MAG2 Not Empty
p_{53}	Extend MAG2's Cylinder *
p_{54}	Retract MAG2's Cylinder *
p_{55}	MAG2's Cylinder Retracted
p_{56}	Turn Conveyor Belt On
p_{57}	
p_{58}	Turn Conveyor Belt On
p_{59}	Extend Left Discharge Cylinder *
p_{60}	Retract Left Discharge Cylinder *
p_{61}	Metal Half-cube
p_{62}	Turn Conveyor Belt On
p_{63}	Extend Right Discharge Cylinder *
p_{64}	Retract Right Discharge Cylinder *
p_{65}	White Half-Cube
p_{66}	Turn Conveyor Belt On
p_{67}	Extend Center Discharge Cylinder *
p_{68}	Retract Center Discharge Cylinder *
p_{69}	
p_{70}	Turn Conveyor Belt On
p_{71}	Turn Conveyor Belt On
p_{72}	Plastic Half-cube Ready
p_{73}	Conveyor Belt Stopped

Table 1.6: Plastic Half-cube Selection Module Transitions.

Transitions	Meaning
t_{46}	$\overline{\text{MAG2 Empty}}$
t_{47}	
t_{48}	MAG2's Cylinder Extended $\uparrow$
t_{49}	MAG2's Cylinder Retracted $\uparrow$
t_{50}	T=0.5s
t_{51}	Presence $\uparrow$ T=0.5s
t_{52}	Metallic Sensor
t_{53}	Proximity Sensor Left Discharge Cylinder $\uparrow$
t_{54}	Left Discharge Cylinder Extended
t_{55}	Left Discharge Cylinder Retracted
t_{56}	$\overline{\text{Metallic Sensor}}$
t_{57}	$\overline{\text{White Color Sensor}}$
t_{58}	Proximity Sensor Right Discharge Cylinder $\uparrow$
t_{59}	Right Discharge Cylinder Extended
t_{60}	Right Discharge Cylinder Retracted
t_{61}	$\overline{\text{White Color Sensor}}$
t_{62}	Concavity Upwards
t_{63}	Proximity Sensor Center Discharge Cylinder $\uparrow$
t_{64}	Center Discharge Cylinder Extended
t_{65}	Center Discharge Cylinder Retracted
t_{66}	
t_{67}	Concavity Downwards
t_{68}	Proximity Sensor End Of Conveyor Belt $\uparrow$
t_{69}	T=0.5s
t_{70}	Proximity Sensor End Of Conveyor Belt $\uparrow\downarrow$
t_{71}	

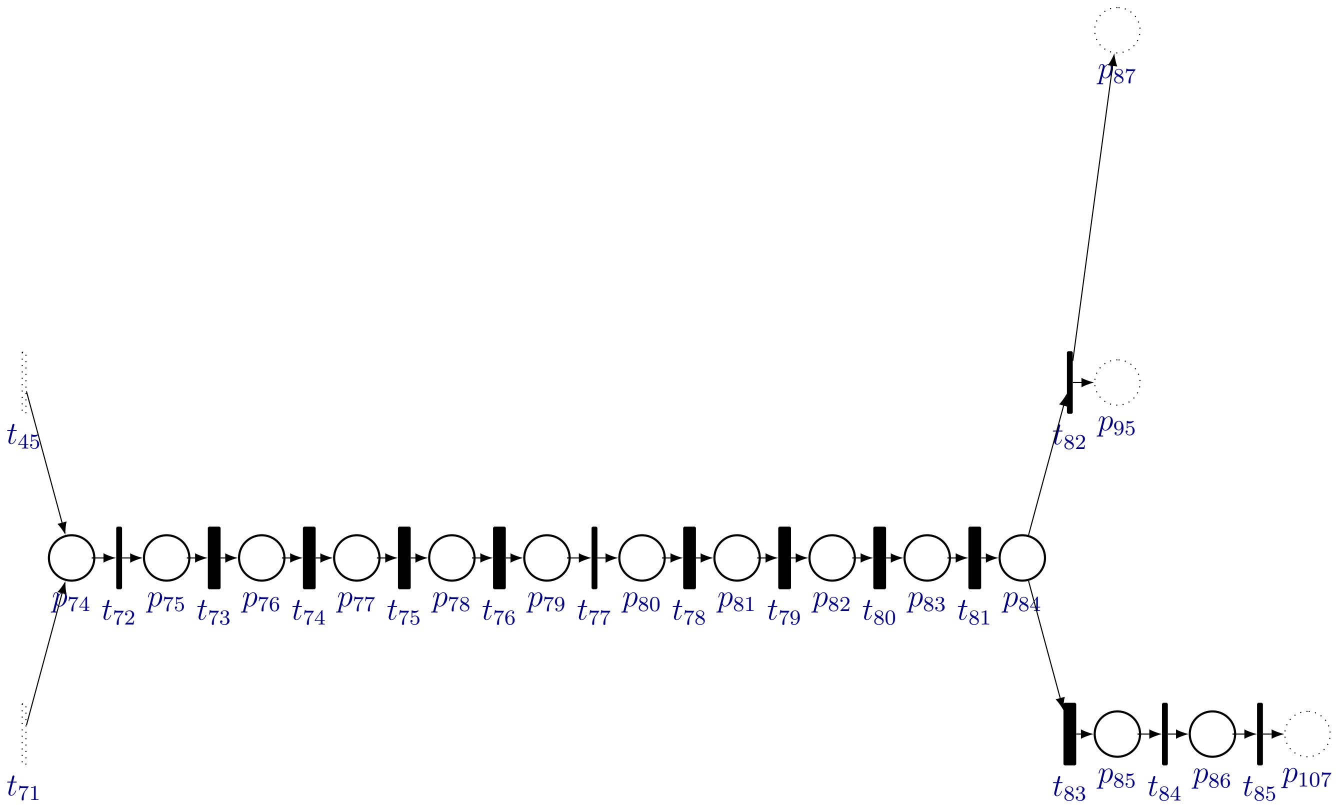

Figure 1.5: Petri net of manipulator taking a cube half from conveyor belt to assembly unit module.

Table 1.7: Arm From Conveyor Belt to Press Module Places.

Places	Meaning
p_{74}	Raise Arm
p_{75}	Raise and Extend Arm, and Turn Vacuum On
p_{76}	Extend Arm and Turn Vacuum On
p_{77}	Raise and Extend Arm and Turn Vacuum On
p_{78}	Raise Arm and Turn Vacuum On
p_{79}	Turn HSC On e Raise Arm, Turn Vacuum On and Rotate Arm CW
p_{80}	Raise and Extend Arm and Turn Vacuum On
p_{81}	Extend Arm and Turn Vacuum On
p_{82}	Extend Arm
p_{83}	Raise and Extend Arm
p_{84}	Raise Arm
p_{85}	Turn HSC On, Raise Arm and Rotate Arm CCW
p_{86}	Raise Arm and HALFPIECECOUNTER:=HALFPIECECOUNTER+1

Table 1.8: Arm From Conveyor Belt to Press Module Transitions.

Transitions	Meaning
t_{72}	Arm Raised
t_{73}	T=1.5s
t_{74}	T=1.5s and Arm Lowered
t_{75}	T=1.5s and Arm Raised
t_{76}	T=1.5s and Arm Raised
t_{77}	ARMCOUNTER = -3330
t_{78}	T=1.5s and Arm Raised
t_{79}	T=1.5s and Arm Lowered
t_{80}	T=1.5s
t_{81}	T=1.5s and Arm Raised
t_{82}	HALFPIECECOUNTER=1, Assembly Unit Holder Extended and Safety Door Opened
t_{83}	T=1.5s, HALFPIECECOUNTER=0 and Raised Arm
t_{84}	ARMCOUNTER = -1690
t_{85}	

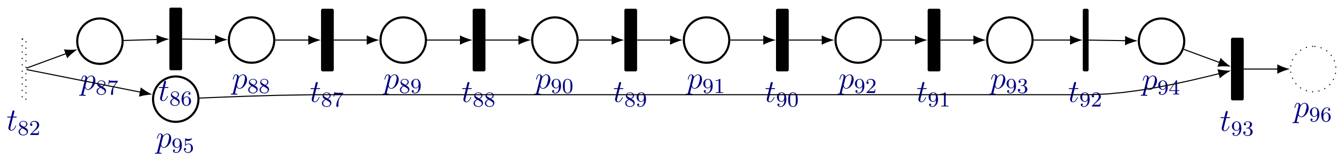

Figure 1.6: Petri net of assembly unit module.

Table 1.9: Assembly Unit Module Places.

Places	Meaning
p_{87}	Retract Assembly Unit Holder *
p_{88}	Close Safety Door *
p_{89}	Lower Press *
p_{90}	Raise Press *
p_{91}	Open Safety Door *
p_{92}	Extend Assembly Unit Holder *
p_{93}	Cube Ready
p_{94}	Extend Arm and Turn Vacuum On
p_{95}	Raise Arm

Table 1.10: Assembly Unit Module Transitions.

Transitions	Meaning
t_{86}	T=1s and Assembly Unit Holder Retracted
t_{87}	T=1s and Safety Door Closed
t_{88}	T=1s
t_{89}	T=1s
t_{90}	T=1s and Safety Door Opened
t_{91}	T=1s and Assembly Unit Holder Extended
t_{92}	
t_{93}	T=1.5s and Arm Extended

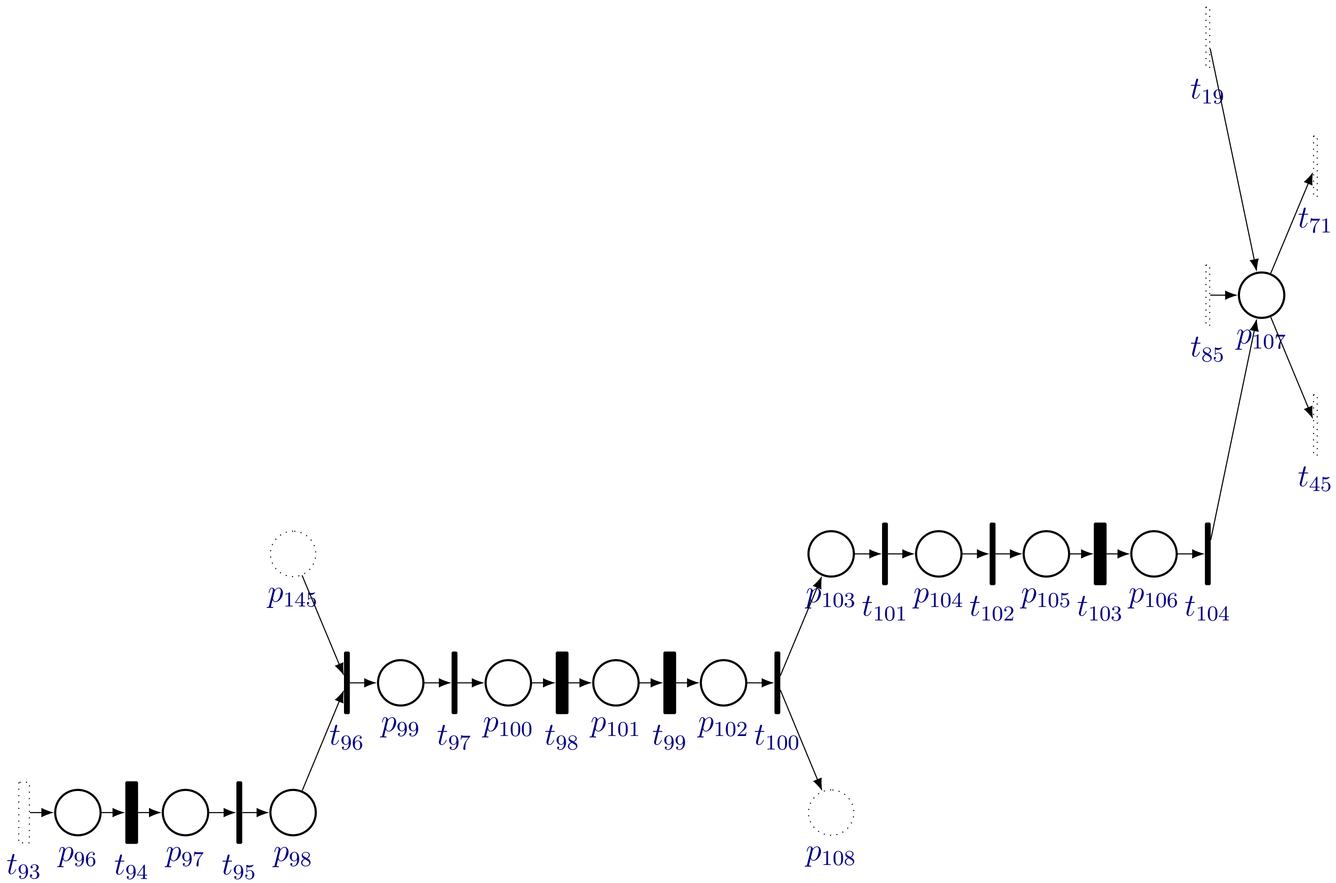

Figure 1.7: Petri net of manipulator taking cube from assembly unit to storage module.

Table 1.11: Arm From Press To Storage Unit Module Places.

Places	Meaning
p_{96}	Extend Arm e Turn Vacuum On
p_{97}	Raise and Extend Arm and Turn Vacuum On
p_{98}	Reset HALFPIECECOUNTER*, Raise Arm and Turn Vacuum On
p_{99}	Turn HSC On, Raise Arm, Turn Vacuum On, Rotate Arm CW
p_{100}	Raise and Extend Arm and Turn Vacuum On
p_{101}	Extend Arm and Turn Vacuum On
p_{102}	Extend Arm
p_{103}	Raise and Extend Arm
p_{104}	Turn Arm CCW
p_{105}	Arm Stoppen
p_{106}	Turn HSC On, Turn Arm CW
p_{107}	Arm Stopped (facing conveyor belt)

Table 1.12: Arm From Press To Storage Unit Module Transitions.

Transitions	Meaning
t_{94}	T=1.5s and Arm Lowered
t_{95}	Arm Raised, Storage Unit Right and Inferior Limit Switches
t_{96}	
t_{97}	ARMCOUNTER = -4920
t_{98}	T=2s
t_{99}	T=2s
t_{100}	Arm Lowered
t_{101}	Arm Raised, Storage Unit Right and Inferior Limit Switches
t_{102}	Inductive Sensor Arm
t_{103}	T=1s
t_{104}	ARMCOUNTER = -1690

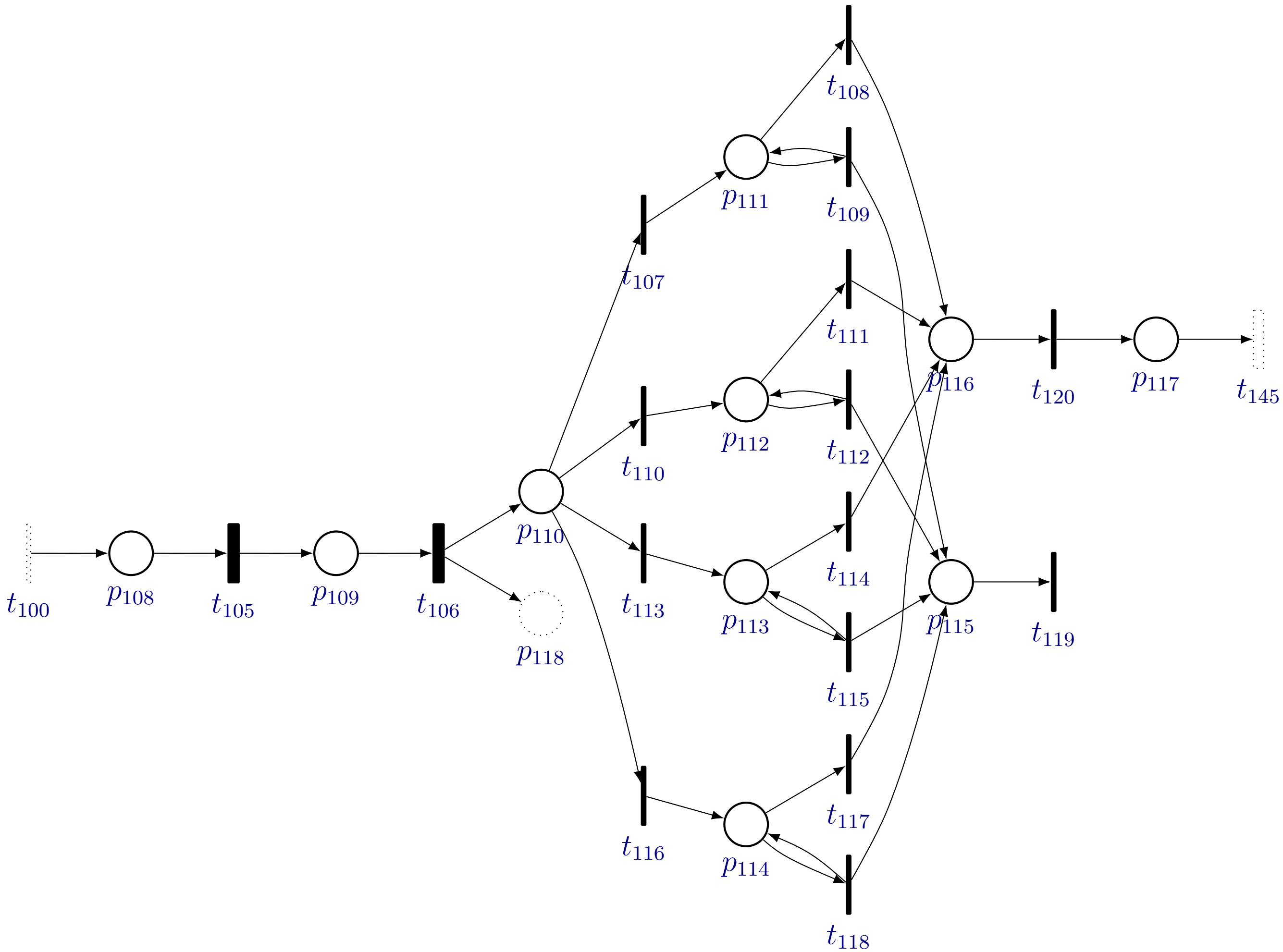

Figure 1.8: Petri net of storage unit positioning module (y axis).

Table 1.13: Storage Unit (Y axis) Module Places.

Places	Meaning
p_{108}	Cube on Storage Unit
p_{109}	Move Storage Unit to the Right
p_{110}	
p_{111}	Move Storage Unit Upwards
p_{112}	Move Storage Unit Upwards
p_{113}	Move Storage Unit Upwards
p_{114}	Move Storage Unit Upwards
p_{115}	COUNTER3:=COUNTER3+1
p_{116}	RESET COUNTER3*
p_{117}	

Table 1.14: Storage Unit (Y axis) Module Transitions.

Transitions	Meaning
t_{105}	T=2s
t_{106}	T=2s
t_{107}	COUNTER2=0
t_{108}	COUNTER3=4
t_{109}	Vertical Encoder
t_{110}	COUNTER2=1
t_{111}	COUNTER3=3
t_{112}	Vertical Encoder
t_{113}	COUNTER2=2
t_{114}	COUNTER3=2
t_{115}	Vertical Encoder
t_{116}	COUNTER2=3
t_{117}	COUNTER3=1
t_{118}	Vertical Encoder
t_{119}	
t_{120}	

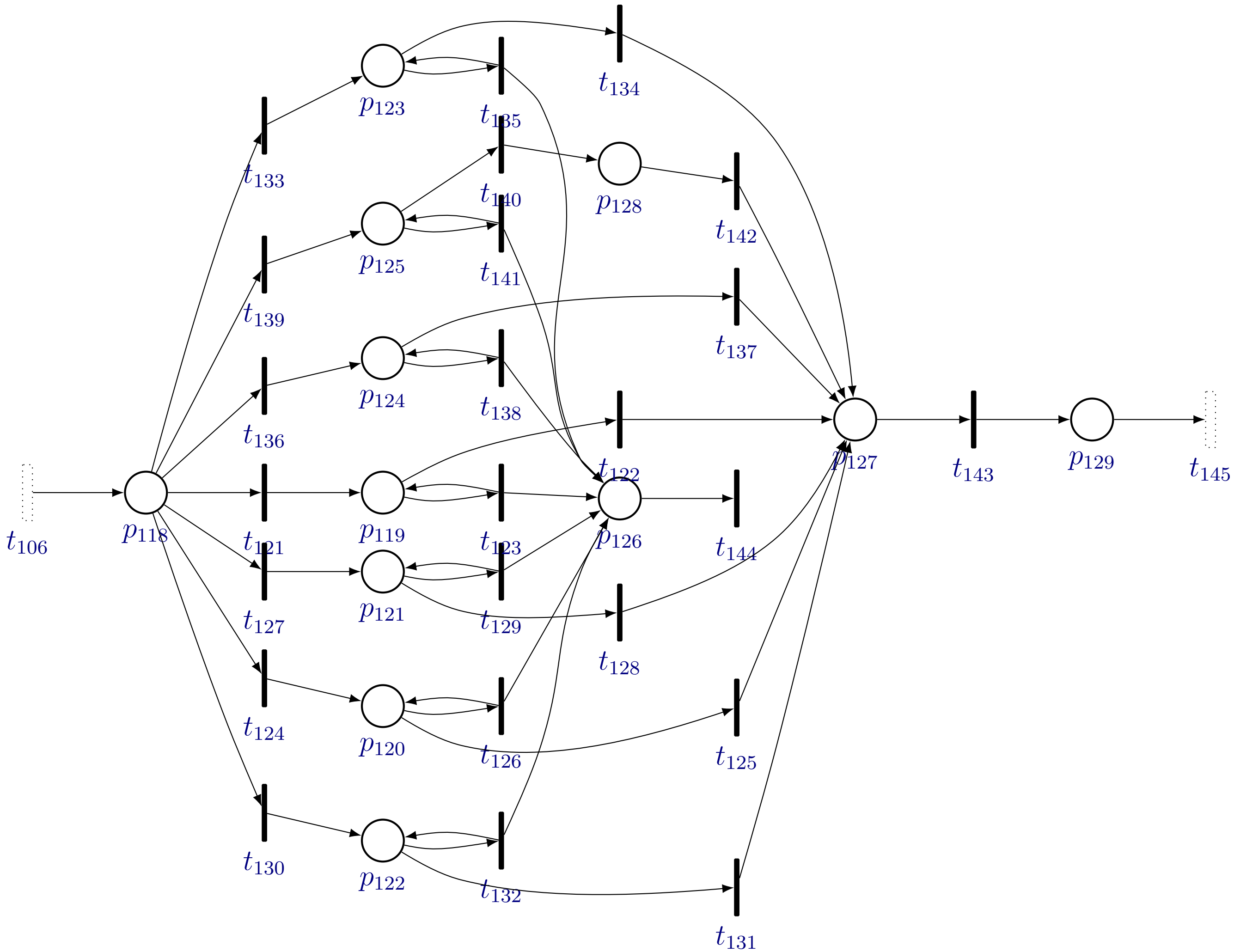

Figure 1.9: Petri net of storage unit positioning module (x axis).

Table 1.15: Storage Unit (X axis) Module Places.

Places	Meaning
p_{118}	COUNTER1:=COUNTER1+1 e COUNTER4:=COUNTER4+1
p_{119}	Move Storage Unit to the Left
p_{120}	Move Storage Unit to the Left
p_{121}	Move Storage Unit to the Left
p_{122}	Move Storage Unit to the Left
p_{123}	Move Storage Unit to the Left
p_{124}	Move Storage Unit to the Left
p_{125}	Move Storage Unit to the Left
p_{126}	COUNTER5:=COUNTER5+1
p_{127}	Reset COUNTER5*
p_{128}	Reset COUNTER4* , COUNTER2:=COUNTER2+1
p_{129}	

Table 1.16: Storage Unit (X axis) Module Transitions.

Transitions	Meaning
t_{121}	COUNTER4=1
t_{122}	COUNTER5=1
t_{123}	Horizontal Encoder
t_{124}	COUNTER4=2
t_{125}	COUNTER5=2
t_{126}	Horizontal Encoder
t_{127}	COUNTER4=3
t_{128}	COUNTER5=3
t_{129}	Horizontal Encoder
t_{130}	COUNTER4=4
t_{131}	COUNTER5=4
t_{132}	Horizontal Encoder
t_{133}	COUNTER4=5
t_{134}	COUNTER5=5
t_{135}	Horizontal Encoder
t_{136}	COUNTER4=6
t_{137}	COUNTER5=8
t_{138}	Horizontal Encoder
t_{139}	COUNTER4=7
t_{140}	COUNTER5=9
t_{141}	Horizontal Encoder
t_{142}	
t_{143}	
t_{144}	

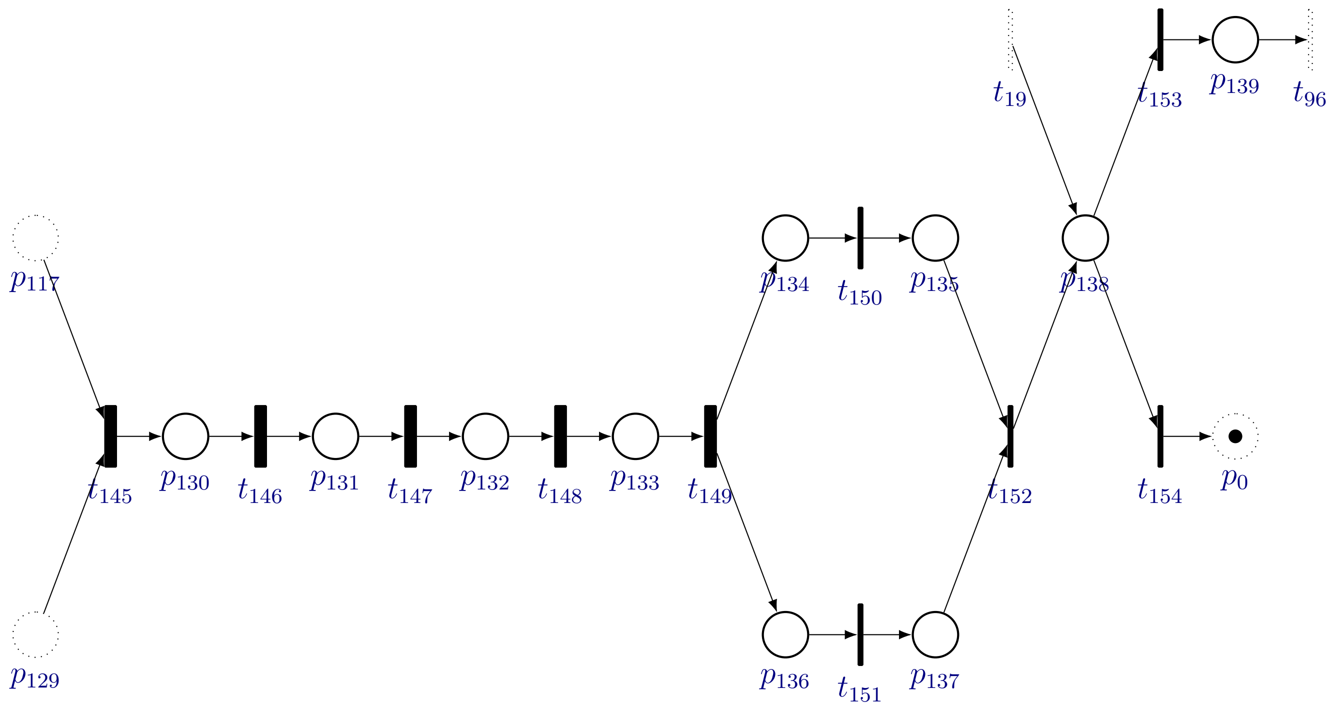

Figure 1.10: Petri net of cube storage module.

Table 1.17: Cube Storage Module Places.

Places	Meaning
p_{130}	Extend Storage Unit
p_{131}	Extend Storage Unit and Move Storage Unit Downwards
p_{132}	Extend Storage Unit
p_{133}	Piece Stored
p_{134}	Move Storage Unit to the Right
p_{135}	Storage Unit Ready (horizontal)
p_{136}	Move Storage Unit Downwards
p_{137}	Storage Unit Ready (vertical)
p_{138}	
p_{139}	Storage Unit Ready

Table 1.18: Cube Storage Module Transitions.

Transitions	Meaning
t_{145}	T=2s
t_{146}	T=3s
t_{147}	T=0.25s
t_{148}	T=3s
t_{149}	T=7s
t_{150}	Storage Unit Right Limit Switch
t_{151}	Storage Unit Inferior Limit Switch
t_{152}	
t_{153}	COUNTER1<28
t_{154}	COUNTER1=28

Chapter 2

Introduction

Chapter 3

Results

3.1 Teste

Chapter 4

Conclusion

Bibliography

CABRAL, F. G., MOREIRA, M. V. "Synchronous Codiagnosability of Modular Discrete-Event Systems", *IFAC-PapersOnLine*, v. 50, n. 1, pp. 6831–6836, 2017.

CABRAL, F. G., MOREIRA, M. V., DIENE, O., et al. "Petri net diagnoser for discrete event systems modeled by finite state automata", *IEEE Transactions on Automatic Control*, v. 60, n. 1, pp. 59–71, 2015a.

CABRAL, F. G., MOREIRA, M. V., DIENE, O. "Online fault diagnosis of modular discrete-event systems". In: *Decision and Control (CDC), 2015 IEEE 54th Annual Conference on*, pp. 4450–4455. IEEE, 2015b.

CASSANDRAS, C. G., LAFORTUNE, S. *Introduction to discrete event systems.* Springer Science & Business Media, 2009.

DAVID, R., ALLA, H. L. *Du Grafcet aux réseaux de Petri.* Hermes, 1989.

FRANÇA, T. C. *Projeto de um sistema supervisório para uma planta mecatrônica de estocagem de Peças.* Projeto de Graduação, Universidade Federal do Rio de Janeiro, 2015.

JOURDAN, G., BOCHMANN, G. V. "On testing 1-safe Petri nets". In: *2009 Third IEEE International Symposium on Theoretical Aspects of Software Engineering*, pp. 275–281. IEEE, 2009.

KUMAR, R., TAKAI, S. "Comments on "Polynomial Time Verification of Decentralized Diagnosability of Discrete Event Systems" versus "Decentralized Failure Diagnosis of Discrete Event Systems": Complexity Clarification", *IEEE Transactions on Automatic Control*, v. 59, n. 5, pp. 1391–1392, 2014.

LANCELLOTE JÚNIOR, F. P. *Automação de uma planta mecatrônica modelada por uma rede de petri interpretada para controle*. Projeto de Graduação, Universidade Federal do Rio de Janeiro, 2014.

LUCIO, M. L. *Diagnóstico de falhas sincronizado de uma planta de manufatura*. Projeto de Graduação, Universidade Federal do Rio de Janeiro, 2015.

MOREIRA, M. V., LESAGE, J.-J. "Enhanced discrete event model for system identification with the aim of fault detection", *IFAC-PapersOnLine*, v. 51, n. 7, pp. 160–166, 2018.

MOREIRA, M. V., BASILIO, J. C., CABRAL, F. G. ""Polynomial Time Verification of Decentralized Diagnosability of Discrete Event Systems" Versus "Decentralized Failure Diagnosis of Discrete Event Systems: A Critical Appraisal", *IEEE Transactions on Automatic Control*, v. 61, n. 1, pp. 178–181, 2016.

OLIVEIRA, V. D. S. L. *Protocolo de comunicação profinet para redes de automação*. Projeto de Graduação, Universidade Federal do Rio de Janeiro, 2016.

VERAS, M. Z., CABRAL, F. G., MOREIRA, M. V. "Distributed Synchronous Diagnosability of Discrete-Event Systems", *IFAC-PapersOnLine*, v. 51, n. 7, pp. 88–93, 2018.

Appendix A

Complete Petri Net