AN INTEGRATED APPROACH OF ARTIFICIAL NEURAL NETWORKS AND SYSTEM DYNAMICS FOR ESTIMATING PRODUCT COMPLETION TIME IN A SEMIAUTOMATIC PRODUCTION

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Abstrak

Penentuan masa siap dalam penghasilan produk baru menjadi salah satu indikator yang penting kepada pengilang bagi penghantaran barangan kepada pelanggan. Kegagalan menepati penghantaran pada masanya, atau dikenali sebagai kelewatan, menyumbang kepada kos penghantaran melalui udara yang tinggi serta ketidakupayaan pengeluaran oleh rantaian bekalan. Ketidakpastian masa siap menyebabkan masalah besar kepada pengilang yang menghasilkan produk audio pembesar suara melalui saluran pengeluaran separuh automatik. Justeru, objektif utama kajian ini adalah untuk membangunkan model tergabung dengan mempertingkatkan penggunaan kaedah rangkaian neural buatan (ANN) dan system dinamik (SD) bagi menganggarkan masa kitaran. Sebanyak tiga jenis model berasaskan perseptron berbilang lapisan (MLP) telah dibangunkan dengan perbezaaan senibina rangkaian untuk menganggarkan masa kitaran. Tambahan, satu persamaan kadar momentum yang telah diformulasi adalah dicadangkan untuk setiap model bagi memperbaiki proses pembelajaran yang mana rangkaian 3-2-1 muncul sebagai rangkaian terbaik dengan nilai kesilapan min kuasa dua yang terkecil. Seterusnya, keputusan anggaran oleh rangkaian 3-2-1 disimulasikan melalui model SD yang dibangunkan untuk menilai pencapaian masa siap dari segi jumlah produk, keletihan operator pengeluaran dan skor beban kerja pengeluaran. Kejayaan model tergabung ANNSD yang disarankan juga bergantung kepada perkaitan pengkali yang dicadangkan untuk gambarajah bulatan penyebab (CLD) bagi mengenalpasti punca yang paling berpengaruh ke atas masa persiapan. Hasilnya, model tergabung ANNSD yang dicadangkan memberi panduan yang bermakna kepada pengilang dalam menentukan faktor yang paling berpengaruh ke atas masa siap yang mana masa diguna untuk melengkapkan produk audio baru dapat dianggarkan dengan tepat. Kesannya, penghantaran barangan menjadi lancar dan tepat pada masa manakala permintaan pelanggan dapat dipenuhi dengan jayanya.

Kata Kunci: Rangkaian neural buatan, Sistem dinamik, Masa siap, Kadar momentum, Pengeluaran separuh automatik.

Abstract

The determination of completion time to produce a new product is one of the most important indicators for manufacturers in delivering goods to customers. Failure to fulfil delivery on-time or known as tardiness contributes to a high cost of air shipment and production line down at other entities within the supply chain. The uncertainty of completion time has created a big problem for manufacturers of audio speakers which involved semiautomatic production lines. Therefore, the main objective of this research is to develop an integrated model that enhances the artificial neural networks (ANN) and system dynamics (SD) methods in estimating completion time focusing on the cycle time. Three ANN models based on multi-layer perceptron (MLP) were developed with different network architectures to estimate cycle time. Furthermore, a proposed momentum rate equation was formulated for each model to improve learning process, where the 3-2-1 network emerged as the best network with the smallest mean square error. Subsequently, the estimated cycle time of the 3-2-1 network was simulated through the development of an SD model to evaluate the performance of completion time in terms of product quantity, manpower fatigue and production workload scores. The success of the proposed integrated ANNSD model also relied on a proposed coefficient correlation of causal loop diagram (CLD) to identify the most influential factor of completion time. As a result, the proposed integrated ANNSD model provided a beneficial guide to the company in determining the most influential factor on completion time so that the time to complete a new audio product can be estimated accurately. Consequently, product delivery was smooth for on-time shipment while successfully fulfilling customers' demand.

Keywords: Artificial neural networks, System dynamics, Completion time, Momentum rate, Semiautomatic production.

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List of Abbreviations

ABS	Agent Based Simulation
ANN	Artificial Neural Networks
ART	Adaptive Resonance Theory
BP	Backpropagation
CBR	Case Based Reasoning
CLD	Causal Loop Diagram
DES	Discrete Event Simulation
EOL	End-of-life
MLP	Multilayer Perceptron
MSE	Mean Square Error
MWH	Material Warehouse
SFD	Stock Flow Diagram
SOM	Self-Organizing Maps
SVM	Support Vector Machine
VSM	Viable System Model

CHAPTER ONE
INTRODUCTION

In today's competitive manufacturing environment, completion time is crucial for manufacturer in reflecting the delivery performance on time (Zhou & Chai, 1996; Behdani, Lukszo, Adhitya & Srinivasian, 2007; Mussa, 2009; Aslam, 2013; Wang & Jiang, 2017). Time is one of the most important dimensions of service quality for manufactured products that a customer demands (Mussa, 2009; Albrecht & Steinrücke, 2017). In order to ensure delivery due date can be fulfilled, production operation that minimally disruptive becomes a vital task (Leus & Herroelen, 2007). Failure in fulfilling distribution date on time will ultimately result in the interruption of production processes. Consequently, the interruption will cause delays in delivery which may incur high costs of shipment (such as by air shipment to rush delivery), and may eventually tarnish the image of the manufacturer.

1.1 Importance of the Manufacturing Sector

The manufacturing sector has been recorded as the most crucial sector (as compared to other industries) and contributed almost RM 70.4 billion to the Malaysian economy in the first quarter of 2018 through export activities (Department of Statistics Malaysia [DOSM], 2018). Thus, a rapid transformation is progressively carried out by the Malaysia government in strengthening the manufacturing sector, especially to cope with the challenges of the Industrial Revolution 4.0 (IR 4.0); a smart and flexible manufacturing operation through the integration of computational and physical processes (Bortolini, Ferrari, Gamberi, Pilati, & Faccio, 2017; Li, Hou,

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APPENDIX A
OPEN-ENDED QUESTIONS

The list of open-ended questions given to Senior Planners, Executive and Supervisor from the Production Control Department and Production Department.

1) What is the challenge(s) facing by management to fulfil customer demand on-time?

____

____

____

2) What is the factor(s) contributes to tardiness of completion time in the semiautomatic production line?

____

____

____

3) How the factors are recorded/ documented?

____

____

____

APPENDIX B

VALIDATION FROM THE EXPERTS OF A COMPANY

FLEXI ACOUSTICS SDN. BHD. 974200-K

(Formerly Known as Onkyo Jitra Malaysia Sdn. Bhd.)
Plot 105, Kawasan Perusahaan Darulaman, Bandar Darulaman, 06000 Jitra, Kedah Darul Aman.
Tel: +604-9175688 Fax: +604-9175788 Email: sales@flexi-acoustics.com
Website: www.flexi-acoustic.com

26-May, 2017

To whom it may concern,

We hereby verify that the Phd candidate, Ahmad Afif Ahmarofi, from School of Quantitative Sciences, Universiti Utara Malaysia has conducted several consultations with person in charge (PIC) from Department of Control Production and Department of Production of this company for his research thesis.

During the consultation, he had interviewed us with several questions regarding the operation and management of semiautomatic production line concerning completion time problem as well as other factors associated with it. Moreover, he had proposed some of the scientific approaches such as system dynamics and artificial neural networks to overcome the problems as highlighted during the session.

We found that his finding and solutions in scientific approach are acceptable and practical as a beneficial contribution towards the completion time problem which could improve our performance. In addition, the session is a good exposure to the management in industrial sector to tackle the rapid challenges in nowadays market place.

Thank you.

Yours sincerely,

Puspa a/p Ramiah
(Executive of Production Control Department)

Nor'aini Bt. Saad
(Planner of Production Control Department)

Ida Rahaiza Bt. Abd. Rahim
(Executive of Human Resource Department)

FLEXI ACOUSTICS SDN. BHD.
Plot 105, Kawasan Perusahaan Darulaman,
Bandar Darulaman, 06000 Jitra,
Kedah Darul Aman.
Tel: 04-9175688 (Hunting Line) Fax: 04-9175788

APPENDIX C

SIMULATION CODE OF SFD IN VENSIM

desired material order rate=adjustment material on order/supplier lead time delivery
~Unit: pieces/Hour

supplier lead time delivery=1
~Unit:Hour

Finished goods inventory= INTEG (STEP(production completion time-shipment rate,0),0)
~Unit: pieces

Work in process= INTEG (production start rate-production completion time,0)
~Unit: pieces

number of manpower=30
~Unit: person

number of manpower per hour=(number of manpower*attendance rate)/standard working hour
~Unit: person/Hour

attendance rate=1
~Unit: Dmnl |

cycle time=5
~Unit: second/pieces

standard working hour in seconds=3600
~Unit: second/Hour

standard completion rate=standard working hour in seconds/cycle time
~Unit: pieces/Hour

effect of schedule pressure on working hour=schedule pressure*standard working hour
~Unit: Hour

production utilization=effect of schedule pressure on working hour/standard working hour
~Unit: Dmnl

delivery rate=1
~Unit: Hour

time per task= 0.0416667
~Unit: person*Hour/pieces

production completion time=potential completion time*Work in process
~Unit: pieces/Hour

shipment rate=Finished goods inventory/delivery rate
~Unit: pieces/Hour

standard working hour=1
~Unit: Hour

potential completion time= (number of manpower per hour*machine breakdown rate*effect of schedule pressure on working hour*effect of fatigue on productivity)/time per task
~Unit: pieces/Hour/pieces

table of fatigue([(0,0)-(1.7,2)],(0,0),(1,1),(1.25,1.25),(1.7,1.7))
~Unit: Dmnl

machine breakdown rate=0.00138889
~Unit: 1/pieces

effect of fatigue on productivity=table of fatigue(production utilization)
~Unit: Dmnl

schedule pressure=desired completion rate/standard completion rate
~Unit: Dmnl

desired completion rate=Work in process/target completion hour
~Unit: pieces/Hour

target completion hour=1
~Unit: Hour

reorder material=desired production start rate*material reject rate
~Unit: pieces

adjustment material on order=Material warehouse inventory+reorder material
~Unit: pieces

material supply rate=Material warehouse inventory*material preparation rate
~Unit: pieces/Hour

material availability ratio=Material warehouse inventory/desired production start rate
~Unit: Dmnl

material preparation=1
~Unit: Hour

material reject rate=0
~Unit: Dmnl

material preparation rate=material availability ratio/material preparation
~Unit: 1/Hour

material order rate=desired material order rate
~Unit: pieces/Hour

production start rate= STEP(desired production start from material,0)
~Unit: pieces/Hour

desired production start rate=5040
~Unit: pieces

desired production start from material=material supply rate/material usage per unit
~Unit: pieces/Hour

material usage per unit=7
~Unit: Dmnl

Material warehouse inventory= INTEG (material order rate-material supply rate,5040)
~Unit: pieces

```
*****************************************************

.Control
*****************************************************~
                    Simulation Control Parameters

FINAL TIME  = 9
          ~         Unit: Hour
          ~         /The final time for the simulation/

INITIAL TIME  = 0
          ~         Unit: Hour
          ~         /The initial time for the simulation/

SAVEPER  = TIME STEP
          ~         Unit: Hour [0,?]
          ~         /The frequency with which output is stored/
          |

TIME STEP  = 1
          ~         Unit: Hour [0,?]
          ~         /The time step for the simulation/

\\\---/// Sketch information - do not modify anything except names
V300  Do not put anything below this section - it will be ignored
*View 1
$192-192-192,0,Times New Roman|16||0-0-0|0-0-0|0-0-255|-1--1--1|-1--1--1|96,96,65,0
10,1,Material warehouse inventory,179,344,47,28,3,131,0,0,0,0,0,0
12,2,48,-147,327,10,8,0,3,0,0,-1,0,0,0
1,3,5,1,4,0,0,22,0,0,0,-1--1--1,,1|(81,329)|
1,4,5,2,100,0,0,22,0,0,0,-1--1--1,,1|(-59,329)|
11,5,48,24,329,6,8,34,3,0,0,1,0,0,0
10,6,material order rate,24,363,66,26,40,131,0,0,-1,0,0,0
12,7,48,539,332,10,8,0,3,0,0,-1,0,0,0
1,8,10,7,4,0,0,22,0,0,0,-1--1--1,,1|(428,328)|
1,9,10,1,100,0,0,22,0,0,0,-1--1--1,,1|(271,328)|
11,10,48,322,328,6,8,34,3,0,0,1,0,0,0
10,11,material supply rate,322,362,79,26,40,131,0,0,-1,0,0,0
10,12,adjustment material on order,37,466,75,23,8,3,0,0,0,0,0,0
10,13,desired material order rate,-131,418,70,23,8,3,0,0,0,0,0,0
1,14,1,12,1,0,0,0,0,64,0,-1--1--1,,1|(138,425)|
1,15,12,13,1,0,0,0,0,64,0,-1--1--1,,1|(-48,475)|
1,16,13,6,1,0,0,0,0,64,0,-1--1--1,,1|(-73,340)|
10,17,desired production start from material,594,446,82,23,8,3,0,0,0,0,0,0
10,18,desired production start rate,394,587,82,23,8,3,0,0,0,0,0,0
10,19,material usage per unit,603,529,64,23,8,3,0,0,0,0,0,0
1,20,19,17,1,0,0,0,0,64,0,-1--1--1,,1|(616,492)|
1,21,11,17,1,0,0,0,0,64,0,-1--1--1,,1|(462,362)|
10,22,Work in process,1117,195,40,20,3,3,0,0,0,0,0,0
12,23,48,719,190,10,8,0,3,0,0,-1,0,0,0
1,24,26,22,4,0,0,22,0,0,0,-1--1--1,,1|(994,190)|
1,25,26,23,100,0,0,22,0,0,0,-1--1--1,,1|(814,190)|
11,26,48,906,190,6,8,34,3,0,0,1,0,0,0
10,27,production start rate,906,217,50,19,40,3,0,0,-1,0,0,0
1,28,17,27,1,0,0,0,0,64,0,-1--1--1,,1|(650,276)|
1,29,1,10,1,0,0,0,0,64,0,-1--1--1,,1|(250,296)|
10,30,material availability ratio,262,454,72,23,8,3,0,0,0,0,0,0
10,31,material preparation rate,396,419,69,23,8,3,0,0,0,0,0,0
10,32,material preparation,486,510,54,29,8,131,0,4,0,0,0,0,-1--1--1,128-192-255,|12||0-0-0
```

1,33,1,30,1,0,0,0,0,64,0,-1--1--1,,1|(199,409)|
1,34,32,31,1,0,0,0,0,64,0,-1--1--1,,1|(461,451)|
1,35,31,11,1,0,0,0,0,64,0,-1--1--1,,1|(377,348)|
1,36,30,31,1,0,0,0,0,64,0,-1--1--1,,1|(333,461)|
10,37,reorder material,147,559,36,23,8,3,0,0,0,0,0,0
10,38,material reject rate,257,590,63,23,8,3,0,0,0,0,0,0
1,39,37,12,1,0,0,0,0,64,0,-1--1--1,,1|(126,485)|
1,40,38,37,1,0,0,0,0,64,0,-1--1--1,,1|(226,543)|
1,41,18,30,1,0,0,0,0,64,0,-1--1--1,,1|(373,505)|
1,42,18,37,1,0,0,0,0,64,0,-1--1--1,,1|(240,655)|
10,43,Finished goods inventory,1716,203,51,30,3,131,0,0,0,0,0,0
1,44,46,43,4,0,0,22,0,0,0,-1--1--1,,1|(1560,193)|
1,45,46,22,100,0,0,22,0,0,0,-1--1--1,,1|(1300,193)|
11,46,220,1449,193,6,8,34,131,0,0,1,0,0,0
10,47,production completion time,1449,224,72,23,40,131,0,4,-1,0,0,0,-1--1--1,0-255-0,|12||0-0-0
1,48,22,46,1,0,0,0,0,64,0,-1--1--1,,1|(1181,153)|
10,49,desired completion rate,1028,310,69,23,8,3,0,0,0,0,0,0
10,50,target completion hour,878,359,73,23,8,3,0,0,0,0,0,0
12,51,48,1951,188,10,8,0,3,0,0,-1,0,0,0
1,52,54,51,4,0,0,22,0,0,0,-1--1--1,,1|(1893,194)|
1,53,54,43,100,0,0,22,0,0,0,-1--1--1,,1|(1800,194)|
11,54,48,1840,194,6,8,34,3,0,0,1,0,0,0
10,55,shipment rate,1840,213,58,13,40,3,0,0,-1,0,0,0
10,56,schedule pressure,1100,439,39,23,8,3,0,0,0,0,0,0
10,57,standard completion rate,963,529,69,23,8,3,0,0,0,0,0,0
10,58,effect of schedule pressure on working hour,1258,511,89,34,8,3,0,4,0,0,0,0,-1--1--1,0-255-0,|16||0-0-0
10,59,standard working hour,1361,620,60,23,8,3,0,0,0,0,0,0
10,60,production utilization,1441,515,48,23,8,3,0,0,0,0,0,0
10,61,potential completion time,1471,344,72,23,8,3,0,0,0,0,0,0
10,62,number of manpower per hour,1717,404,85,23,8,3,0,0,0,0,0,0
10,63,time per task,1658,319,55,13,8,3,0,0,0,0,0,0
10,64,machine breakdown rate,1600,259,65,19,8,3,0,4,0,0,0,0,-1--1--1,128-192-255,|12||0-0-0
10,65,table of fatigue,1648,541,34,23,8,3,0,0,0,0,0,0
10,66,effect of fatigue on productivity,1532,455,84,23,8,3,0,4,0,0,0,0,-1--1--1,0-255-0,|16||0-0-0
1,67,22,49,1,0,0,0,0,64,0,-1--1--1,,1|(1045,238)|
1,68,49,56,1,0,0,0,0,64,0,-1--1--1,,1|(1036,380)|
1,69,56,58,1,0,0,0,0,64,0,-1--1--1,,1|(1170,485)|
1,70,58,60,1,0,0,0,0,64,0,-1--1--1,,1|(1350,534)|
1,71,59,60,1,0,0,0,0,64,0,-1--1--1,,1|(1425,576)|
1,72,60,66,1,0,0,0,0,64,0,-1--1--1,,1|(1499,501)|
1,73,65,66,1,0,0,0,2,64,0,-1--1--1,|16||0-0-0,1|(1618,481)|
1,74,66,61,1,0,0,0,2,64,0,-1--1--1,|16||0-0-0,1|(1525,393)|
1,75,58,61,1,0,0,0,0,64,0,-1--1--1,,1|(1398,461)|
1,76,64,61,1,0,0,0,0,64,0,-1--1--1,,1|(1530,276)|
1,77,63,61,1,0,0,0,0,64,0,-1--1--1,,1|(1569,310)|
1,78,62,61,1,0,0,0,0,64,0,-1--1--1,,1|(1627,359)|
1,79,61,47,1,0,0,0,0,64,0,-1--1--1,,1|(1480,282)|
1,80,50,49,1,0,0,0,0,64,0,-1--1--1,,1|(921,306)|
1,81,57,56,1,0,0,0,0,64,0,-1--1--1,,1|(991,450)|
1,82,43,54,1,0,0,0,0,64,0,-1--1--1,,1|(1786,145)|
10,83,delivery rate,1896,131,53,13,8,3,0,0,0,0,0,0
1,84,83,54,1,0,0,0,0,64,0,-1--1--1,,1|(1895,161)|
12,85,0,416,67,378,28,3,135,0,12,-1,0,0,0,-1--1--1,128-192-255,|30||0-0-0
INPUT FROM ANN PREDICTION RESULT
12,86,0,447,128,409,24,3,135,0,12,-1,0,0,0,-1--1--1,0-255-0,|30||0-0-0
OBSERVATION OF PERFORMANCE OUTPUT
10,87,number of manpower,1879,411,49,22,8,131,0,4,0,0,0,0,-1--1--1,128-192-255,|12||0-0-0
10,88,standard working hour,1834,504,71,26,8,130,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128

1,89,87,62,1,0,0,0,0,64,0,-1--1--1,,1|(1789,383)|
1,90,88,62,1,0,0,0,0,64,0,-1--1--1,,1|(1753,456)|
1,91,59,58,1,0,0,0,0,64,0,-1--1--1,,1|(1295,582)|
10,92,cycle time,946,632,43,18,8,131,0,4,0,0,0,0,-1--1--1,128-192-255,|12||0-0-0
10,93,standard working hour in seconds,800,516,75,23,8,3,0,0,0,0,0,0
1,94,93,57,1,0,0,0,0,64,0,-1--1--1,,1|(866,477)|
1,95,92,57,1,0,0,0,0,64,0,-1--1--1,,1|(965,594)|
10,96,attendance rate,1827,341,46,23,8,3,0,0,0,0,0,0
1,97,96,62,1,0,0,0,0,64,0,-1--1--1,,1|(1747,351)|
10,98,production completion time,744,680,78,23,8,130,0,3,-1,0,0,0,128-128-128,0-0-0,|12||128-128-128
10,99,supplier lead time delivery,15,589,72,23,8,3,0,0,0,0,0,0
1,100,99,13,1,0,0,0,0,64,0,-1--1--1,,1|(-83,525)|
\\\---/// Sketch information - do not modify anything except names
V300 Do not put anything below this section - it will be ignored
*View 2
$192-192-192,0,Times New Roman|12||0-0-0|0-0-0|0-0-255|-1--1--1|-1--1--1|96,96,100,0