

Operations Research Proceedings

Natalia Chervet · Jan Fabian Ehmke
Ralf Borndorfer Editors

Operations Research Proceedings 2017

Selected Papers of the Annual
International Conference of the
German Operations Research Society
(GOR), Freie Universität Berlin,
Germany, September 6–8, 2017

[HOME](#) [LOG IN](#) [ARCHIVE](#) [CALL FOR PAPER](#) [REGISTRATION](#)

[VENUE](#) [VISA](#)

Home > International Conference on Operational Research (interIOR) 2017 > International Conference on Operational Research 2017

International Conference on Operational Research 2017

The Department of Mathematics University of Sumatera Utara is pleased to announce the 4th International Conference on Operational Research (InteriOR 2017). The InteriOR is held every two years. The first InteriOR was held in 2011. The InteriOR 2017 will be held at Grand Aston City Hall Hotel, Medan, Indonesia on August 21-23, 2017 with the theme "Better Living With Operation Research". The objective of the conference is to provide a forum for researchers, lecturers, educators, students and practitioners in all related disciplines to discuss, share, exchange and to extend their knowledge of new advances on theories and practices in mathematics, particularly in operations research.

KEYNOTE SPEAKERS



Prof. Dr. Gerhard W.

Weber

(Middle East
Technological University,
Turkey)



Prof. Dr. Abdel Salhi

(University of Essex,
United Kingdom)



Prof. Dr. Erwin Pesch

(Universität Siegen,
Germany)



IMPORTANT DATES

Registration:

April 01, 2017

Abstracts Submission

Deadline:

April 30, 2017

May 30, 2017

June 15, 2017

Notification of Acceptance

(Abstracts):

May 31, 2017

June 15, 2017

June 30, 2017

Full Paper Submission

Deadline:

June 17, 2017

July 07, 2017

July 15, 2017

Notification of Acceptance

(Full Paper):

July 17, 2017

July 31, 2017

August 10, 2017

Conference:

August 21 - 23, 2017

USER

Username _____

Password _____

Remember me

Log In

NOTIFICATIONS



Prof. Dr. Katsunori Ano

(Shibaura Institute of
Technology, Japan)



Prof. Dr. Yong Hong

Wu
(Curtin University,
Australia)



Dr. Elise del Rosario

(Operations Research
Society, Philippines)

[View](#)

[Subscribe](#) /
[Unsubscribe](#)

HONORARY BOARD

Prof. Dr. Runtung Sitepu (Rector, University of Sumatera Utara (USU))
Dr. Kerista Sebayang (Dean of Faculty of Mathematics and Natural Science)

INTERNATIONAL BOARD

Prof. Dr. Herman Mawengkang (University of Sumatera Utara, Indonesia)
Prof. Gerhard W. Weber (Middle East Technological University, Turkey)

SCIENTIFIC COMMITTEE

Prof. Dr. Abdel Salhi (University of Essex, United Kingdom)
Prof. Dr. Erwin Pesch (Universität Siegen, Germany)
Prof. Dr. Kok Lay Teo (Curtin University, Australia)
Prof. Dr. Masaji Watanabe (Okayama University, Japan)
Prof. Dr. Ismail Bin Mohd (Universiti Malaysia Perlis, Malaysia)
Prof. Dr. Darwin Sitompul (University of Sumatera Utara, Indonesia)
Prof. Dr. Edy Tri Baskoro (Institut Teknologi Bandung, Indonesia)
Prof. Dr. Sudrajat Supian (Universitas Padjajaran, Indonesia)
Prof. Dr. Agus Suryanto (Brawijaya University, Indonesia)
Prof. Dr. Tulus (University of Sumatera Utara, Indonesia)
Prof. Dr. Opim Salim Sitompul (University of Sumatera Utara, Indonesia)
Prof. Dr. Marwan Ramli (Syiah Kuala University, Indonesia)
Prof. Dr. Anton Abdulbasah Kamil (Telkom University, Indonesia)
Associate Prof. Adam Baharun (Universiti Sains Malaysia, Malaysia)
Dr. P. Vasant (University Technology Petronas, Malaysia)
Dr. Elise del Rosario (Operations Research Society, Philippines)
Dr. Mahyuddin K.M. Nasution (University of Sumatera Utara, Indonesia)
Dr. Eng. Himsar Ambarita (University of Sumatera Utara, Indonesia)
Dr. Fahmi F. (University of Sumatera Utara, Indonesia)
Dr. Tulus Ikhsan Nasution (University of Sumatera Utara, Indonesia)
Dr. Intan Muchtadi-Alamsyah (Institut Teknologi Bandung, Indonesia)
Dr. MDH. Gamal (Universitas Riau, Indonesia)
Dr. Elvina Herawati (University of Sumatera Utara, Indonesia)

ORGANIZING COMMITTEE

Chairman : Prof. Dr. Saib Suwilo

Co-chair : Prof. Dr. Herman Mawengkang

**PROCEEDING
PUBLISHER:**

IOP Conference Series *conferences*
Material Science and Engineering (

INDEXED BY:

Scopus[®]

 **THOMSON REUTERS**

 **Compendex IN**

 **IET Inspec** Polymer Libra
NASA Astrophysics Data Syst
Chemical Abstracts Service

**TEMPLATES AND
GUIDELINES**



ORGANIZER



Department of Mathematics
Faculty of Mathematics and
Natural Sciences
University of Sumatera Utara

Jalan Bioteknologi No. 1, Kampus
USU
Medan, Sumatera Utara -
Indonesia

LOCAL ORGANIZING COMMITTEE

Director : Dr. Maya Silvi Lydia
Secretary : Dr. Syahril Efendi
Treasurer : Dr. Elly Rosmaini
Executive Members : 1. Dr. Ariswoyo
2. Dr. Mardiningsih
3. Dr. Esther Sorta Mauli Nababan
4. Dr. F. Buulolo
5. Dr. Suyanto
6. Dr. Sawaluddin
7. Dr. Sutarman

© 2017 Department of Mathematics
Jalan Bioteknologi No. 1, Kampus USU, Medan - Indonesia
University of Sumatera Utara

Supported by

Indonesian Mathematical Society

Indonesian Operations Research
Association**CONTACT**

Organizing Committee
InteriOR 2017Email:
interior@usu.ac.id

4th International Conference on Operational Research (InteriOR 2017)

IOP Conference Series: Materials Science and Engineering
Volume 300

Medan, Indonesia
21 - 23 August 2017

Editor:

Herman Mawengkang

ISBN: 978-1-5108-5885-5
ISSN: 1757-8981

Printed from e-media with permission by:

Curran Associates, Inc.
57 Morehouse Lane
Red Hook, NY 12571



Some format issues inherent in the e-media version may also appear in this print version.

Copyright© (2017) by the Institute of Physics
All rights reserved. The material featured in this book is subject to
IOP copyright protection, unless otherwise indicated.

Printed by Curran Associates, Inc. (2018)

For permission requests, please contact the Institute of Physics
at the address below.

Institute of Physics
Dirac House, Temple Back
Bristol BS1 6BE UK

Phone: 44 1 17 929 7481
Fax: 44 1 17 920 0979

techtracking@iop.org

Additional copies of this publication are available from:

Curran Associates, Inc.
57 Morehouse Lane
Red Hook, NY 12571 USA
Phone: 845-758-0400
Fax: 845-758-2633
Email: curran@proceedings.com
Web: www.proceedings.com

Table of contents

Volume 300

4th International Conference on Operational Research (InteriOR) 21–23 August
2017, Medan, Indonesia

Accepted papers received: 10 January 2018
Published online: 15 February 2018

Preface

[4th International Conference on Operational Research \(InteriOR\)](#)

[4th International Conference on Operational Research \(InteriOR\)](#)

[4th International Conference on Operational Research \(InteriOR\)](#)

[Peer review statement](#)

Papers

OR

[Portfolio optimization by using linear programming models based on genetic algorithm](#)

Sukono, Y. Hidayat, E. Lesmana, A. S. Putra, H. Napitupulu and S. Supian.....1

[Solving Quadratic Assignment Problem with Fixed Assignment \(QAPFA\) using Branch and Bound Approach](#)

Sharifah Shuthairah Syed-Abdullah, Syariza Abdul-Rahman, Aida Mauziah Benjamin,
Antoni Wibowo and Ku-Ruhana Ku-Mahamud.....10

[Integer programming of cement distribution by train](#)

Indarsih.....19

[Analysis of portfolio optimization with lot of stocks amount constraint: case study index LQ45](#)

Liem Chin, Erwinna Chendra and Agus Sukmana.....24

[Optimization of Personnel Assignment Problem Based on Traveling Time by Using Hungarian Methods: Case Study on the Central Post Office Bandung](#)

Sudradjat Supian, Sri Wahyuni, Julita Nahar and Subiyanto.....30

[Stochastic Optimization in The Power Management of Bottled Water Production Planning](#)

Budi Antoro, Esther Nababan and Herman Mawengkang.....35

[An Optimization Model For Strategy Decision Support to Select Kind of CPO's Ship](#)

Siti Suaibah Nst, Esther Nababan and Herman Mawengkang.....41

[Data Envelopment Analysis \(DEA\) Model in Operation Management](#)

Meilisa Malik, Syahril Efendi and Muhammad Zarlis.....47

[Expected value based fuzzy programming approach to solve integrated supplier selection and inventory control problem with fuzzy demand](#)

Sutrisno, Widowati, Sunarsih and Kartono.....53

[The Analysis of Forward and Backward Dynamic Programming for Multistage Graph](#)

Anna Angela Sitinjak, Elvina Pasaribu, Justin E Simarmata, Tedy Putra and Herman Mawengkang.....61

[Routing and Scheduling Optimization Model of Sea Transportation](#)

Mika debora br barus, Habib asyrafy, Esther nababan and Herman mawengkang.....67

[Mathematical model of parking space unit for triangular parking area](#)

Intan Syahrini, Teti Sundari, Taufiq Iskandar, Vera Halfiani, Said Munzir and Marwan Ramli.....74

[Data-driven Modelling for decision making under uncertainty](#)

Layla Angria S, Yunita Dwi Sari, Muhammad Zarlis and Tulus.....80

[Estimating Most Productive Scale Size in Data Envelopment Analysis with Integer Value Data](#)

Yunita Dwi Sari, Layla Angria S, Syahril Efendi and Muhammad Zarlis.....86

[Mixed Integer Linear Programming model for Crude Palm Oil Supply Chain Planning](#)

Pasukat Sembiring, Herman Mawengkang, Hendaru Sadyadharma, F. Bu'ulolo and Fajriana.....93

[Optimization Model for Capacity Management and Bed Scheduling for Hospital](#)

Suryati Sitepu, Herman Mawengkang and Ismail Husein.....98

[Periodic Heterogeneous Vehicle Routing Problem With Driver Scheduling](#)

Ellis Mardiana Panggabean, Herman Mawengkang, Zainal Azis and Rina Filia Sari.....105

[Decision Model for Planning and Scheduling of Seafood Product Considering Traceability](#)

Agustin, Herman Mawengkang and Devy Mathelinea.....112

[Optimal Control Inventory Stochastic With Production Deteriorating](#)

Pardi Affandi.....120

[Combinatorial Optimization in Project Selection Using Genetic Algorithm](#)

Sari Dewi and Sawaluddin.....127

[Implementation of pattern generation algorithm in forming Gilmore and Gomory model for two dimensional cutting stock problem](#)

Sisca Octarina, Mutia Radiana and Putra B J Bangun.....132

[An Improved Search Approach for Solving Non-Convex Mixed-Integer Non Linear Programming Problems](#)

Joni Wilson Sitopu, Herman Mawengkang and Riri Syafitri Lubis.....139

[An Integer Programming Model For Solving Heterogeneous Vehicle Routing Problem With Hard Time Window considering Service Choice](#)

Enny Susilawati, Herman Mawengkang and Syahril Efendi.....150

[Discrete Optimization Model for Vehicle Routing Problem with Scheduling Side Cosntraints](#)

Dedy Juliandri, Herman Mawengkang and F. Bu'ulolo.....156

[Model Evaluation To Measuring Efficiencies of ICT Development In Indonesia Region Using DEA](#)

Syahril Efendi, M. Fadly Syahputra and M. Anggia Muchtar.....164

[An Integer Programming Model for Multi-Echelon Supply Chain Decision Problem Considering Inventories](#)

Amin Harahap, Herman Mawengkang, Siswadi and Syahril Effendi.....173

ST

[Model estimation of claim risk and premium for motor vehicle insurance by using Bayesian method](#)

Sukono, Riaman, E. Lesmana, R. Wulandari, H. Napitupulu and S. Supian.....181

[Econometric Model of Rice Policy Based On Presidential Instruction](#)

Surya Abadi Sembiring and Julia Hutauruk.....191

[An Improved Version of the Cervical Vertebral Maturation \(CVM\) Method for the Assessment of Mandibular Growth in Deutero-Malay Sub Race](#)

Fahmi Oscandar, Yuti Malinda, H. Azhari, Nani Murniati, Sing Yeh Ong, Subiyanto and Sudradjat Supian.....197

[The Robustness of Two Independent Samples t Test Using Monte Carlo Simulation with R](#)

Prana Ugiana Gio and Elly Rosmaini.....204

[Spatial hierarchical Bayes estimation of mean years of schooling](#)

Dwi A S Wahyuni, Sutarman Wage and Open Darnius.....209

[Forecasting dengue hemorrhagic fever cases using ARIMA model: a case study in Asahan district](#)

Fazidah A Siregar, Tri Makmur and S Saprin.....215

[Volatility in GARCH Models of Business Tendency Index](#)

Dwi A S Wahyuni, Sutarman Wage and Ateng Hartono.....221

[Model of Decision Making through Consensus in Ranking Case](#)

Gim Tarigan and Open Darnius.....226

[Analysis of forecasting malaria case with climatic factors as predictor in Mandailing Natal Regency: a time series study](#)

D Aulia, S F Ayu and A Matondang.....232

[Estimating parameter of Rayleigh distribution by using Maximum Likelihood method and Bayes method](#)

Fitri Ardianti and Sutarman.....239

AM

[Research of Face Recognition with Fisher Linear Discriminant](#)

R Rahim, T Afriliansyah, H Winata, D Nofriansyah, Ratnadewi and S Aryza.....247

[Station Blackout Analysis of HTGR-Type Experimental Power Reactor](#)

Syarip, Aliq Zuhdi and Sabilul Falah.....252

[Directed Diffusion Modelling for Tesso Nilo National Parks Case Study](#)

Indra Yasri and Ery Safrianti.....260

[An Implementation Of Elias Delta Code And ElGamal Algorithm In Image Compression And Security](#)

Dian Rachmawati, Mohammad Andri Budiman and Cut Amalia Saffiera.....267

[Optimal Path Determination for Flying Vehicle to Search an Object](#)

R. Heru Tjahjana, R. Heri Soelistyo U, L. Ratnasari and B. Irawanto.....273

[Hybrid Cryptosystem Using Tiny Encryption Algorithm and LUC Algorithm](#)

Dian Rachmawati, Amer Sharif, Jaysilen and Mohammad Andri Budiman.....279

[Nonlinear evolution of Benjamin-Feir wave group based on third order solution of Benjamin-Bona-Mahony equation](#)

Zahnur, Vera Halfiani, Salmawaty, Tulus and Marwan Ramli.....286

[Analysis Local Convergence of Gauss-Newton Method](#)

Rahmi Wahidah Siregar, Tulus and Marwan Ramli.....292

[Optimal control for Malaria disease through vaccination](#)

Said Munzir, Muhammad Nasir and Marwan Ramli.....298

[Dynamic Models Increase Understanding of Geometry Through Proof](#)

Sari Adeliza, Tulus and Marwan Ramli.....303

[Mathematical model of snake-type multi-directional wave generation](#)

Muarif, Vera Halfiani, Siti Rusdiana, Said Munzir and Marwan Ramli.....310

[Description of Student's Metacognitive Ability in Understanding and Solving Mathematics Problem](#)

Herlina Ahmad, Fatimah Febryanti, Fatimah Febryanti and Muthmainnah.....316

[Modification of 2-D Time-Domain Shallow Water Wave Equation using Asymptotic Expansion Method](#)

Teuku Khairuman, MN Nasruddin, Tulus and Marwan Ramli.....323

[Mitigating Local Natural Disaster through Social Aware Preparedness Using Complexity Approach](#)

Irwan Supadli, Andini Saputri and Herman Mawengkang.....329

[Sedimentation Optimization on River Dam Flow by Using COMSOL Multiphysics](#)

Tulus, Suriati and T. J. Marpaung.....335

[Conceptual Model for Mitigating Human – Wildlife Conflict based on System Thinking](#)

Pindi Patana, Herman Mawengkang and Maya Silvi Lydia.....341

[Semantic interpretation of search engine resultant](#)

M K M Nasution.....347

[Transmission Dinamics Model Of Dengue Fever](#)

Debora, Rendy and Rahmi.....353

[Information Retrieval on social network: An Adaptive Proof](#)

M Elveny, R Syah, M Elfida and M K M Nasution.....357

[Social network extraction based on Web: 1. Related superficial methods](#)

Mahyuddin Khairuddin Matyuso Nasution.....363

[Enhancing to method for extracting Social network by the relation existence](#)

Maria Elfida, M K Matyuso Nasution and O S Sitompul.....369

[CFD Analysis of Evaporation-Condensation Phenomenon In an Evaporation Chamber of Natural Vacuum Solar Desalination](#)

H Ambarita, A D Ronowikarto, R E T Siregar and E Y Setyawan.....375

[Numerical Study on Radiation Effects to Evaporator in Natural Vacuum Solar Desalination System](#)

R E T. Siregar, A D. Ronowikarto, E Y Setyawan and H Ambarita.....380

[Iterative methods for tomography problems: implementation to a cross-well tomography problem](#)

M F Karadeniz and G W Weber.....386

[Enviromental Health Risks on Community in Coastal Area As a Results The Presence of Pb in Sea Water and Drinking Water.](#)

Sri Malem Indirawati, Setiaty Pandia, Herman Mawengkang and Wirsal Hasan.....394

[Assessment of Seismic Damage on The Exist Buildings Using Fuzzy Logic](#)

USTA Pınar, MOROVA Nihat, Ahmet EVCİ and Serap ERGÜN.....401

[SEM Model Medical Solid Waste Hospital Management In Medan City](#)

Verawaty Simarmata, Setiaty Pandia and Herman Mawengkang.....407

[Developing a feasible neighbourhood search for solving hub location problem in a communication network](#)

Fibri Rakhmawati, Herman Mawengkang, F. Buulolo and Mardiningsih.....414

[Seismic Evaluation of A Historical Structure In Kastamonu - Turkey](#)

USTA Pınar, Asuman Işıl ÇARHOĞLU and Ahmet EVCİ.....420

[Utilization of Cocoa Peel as Biosorbent for Oil and Color Removal in Palm Oil Mill Effluent \(POME\)](#)

S Pandia, A T Hutagalung and A D Siahaan.....427

[A Novelty Design Of Minimization Of Electrical Losses In A Vector Controlled Induction Machine Drive](#)

Solly Aryza, M Irwanto, Zulkarnain Lubis, Andysah Putera Utama Siahaan, Robbi Rahim and Mhd. Furqan.....435

[LISREL Model Medical Solid Infectious Waste Hazardous Hospital Management In Medan City](#)

Verawaty Simarmata, Ungkap Siahaan, Setiaty Pandia and Herman Mawengkang.....442

[Perceptron Genetic to Recognize Opening Strategy Ruy Lopez](#)

Zulfian Azmi and Herman Mawengkang.....449

PM

[Triangle Number of Laurent polynomial for the closed braids \$\sigma^{2j}\$](#)

M K M Nasution, A S Harahap, S Nasution and E Herawati.....457

[Some structural properties of vector valued \$\varphi\$ -function sequence space](#)

S N R Gultom and E Herawati.....463

[Notes on matrix of Fibonacci numbers](#)

Rendy Jehanshah, Yan Putra, Debora E Sirait, Mardiningsih and Zuhri.....468

[On some new normed sequence spaces](#)

G Pranajaya and E Herawati.....474

[Generalized Moore Penrose Inverse of Normal Elements in a Ring with Involution](#)

SRRM Titi Udjiani, Harjito, Suryoto and Nikken Prima P.....480

[The competition index of two-colored non-hamiltonian digraph with two cycles whose lengths differ by three](#)

Hari Sumardi, Saib Suwilo and Elly Rosmaini.....484

[On the 5-Local Profiles of Trees](#)

Efron Manik, Saib Suwilo, Tulus and Opim Salim Sitompul.....490

[Scrambling index of certain primitive graphs consisting of two disjoint odd cycles connected by some paths](#)

Mariana Sitorus, Febryandi Ginting, Putri K Nasution and Sundari Atikah.....496

[Scrambling index of two-colored two-cycles whose lengths differ by four](#)

Tantri O D S Putri, Sawaluddin Nasution and Junior B Pasorong.....501

[Exponent and scrambling index of double alternate circular snake graphs](#)

Sri Rahmayanti, Valdo E Pasaribu, Sawaluddin Nasution and Sishi Liani Salnaz.....507

[Local exponents of a certain class of two-colored Hamiltonian digraphs with two cycles whose lengths \$n\$ and \$n - 3\$](#)

Mardiningsih, Syahriol Sitorus, Raidani and Ferry Safriandi.....511

[Primitive graphs with small exponent and small scrambling index](#)

Ita Y Surbakti, Saib Suwilo, Ericha A Butar-butur and Helda Oktaviani.....518

[The grey Shapley value: an axiomatization](#)

M Ekici, O Palanci and S Z Alparslan Gök.....524

[Bounds for scrambling index of primitive graphs](#)

Shaflina Izar, Mardiningsih, Zuhri and Sylvi Harleni.....531

[An Interactive Strategy for Solving Multi-Criteria Decision Making of Sustainable Land Revitalization Planning Problem](#)

Ruth Mayasari, Herman Mawengkang and Ronal Gomar Purba.....537

[Integer Optimization Model for a Logistic System based on Location-Routing Considering Distance and Chosen Route](#)

Joni Mulyasari, Herman Mawengkang and Syahril Efendi.....543

[Multi-objective model of waste transportation management for crude palm oil industry](#)

Meslin Silalahi, Herman Mawengkang and Nenna Irsa Syahputri.....550

PAPER • OPEN ACCESS

Implementation of pattern generation algorithm in forming Gilmore and Gomory model for two dimensional cutting stock problem

To cite this article: Sisca Octarina *et al* 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **300** 012021

View the [article online](#) for updates and enhancements.

Related content

- [Research council board](#)
- [Boosting Learning Algorithm for Stock Price Forecasting](#)
Chengzhang Wang and Xiaoming Bai
- [Combinatorial Algorithms for Portfolio Optimization Problems – Case of Risk Moderate Investor](#)
A Juarna

Implementation of pattern generation algorithm in forming Gilmore and Gomory model for two dimensional cutting stock problem

Sisca Octarina, Mutia Radiana, Putra B J Bangun

Department of Mathematics, Faculty of Mathematics and Natural Sciences,
Sriwijaya University

e-mail address: s.octarina@gmail.com

Abstract. Two dimensional cutting stock problem (CSP) is a problem in determining the cutting pattern from a set of stock with standard length and width to fulfill the demand of items. Cutting patterns were determined in order to minimize the usage of stock. This research implemented pattern generation algorithm to formulate Gilmore and Gomory model of two dimensional CSP. The constraints of Gilmore and Gomory model was performed to assure the strips which cut in the first stage will be used in the second stage. Branch and Cut method was used to obtain the optimal solution. Based on the results, it found many patterns combination, if the optimal cutting patterns which correspond to the first stage were combined with the second stage.

1. Introduction

The printing industry is trying to increase production on a large scale by managing the use of raw materials (stock). The planning aims to determine the minimum amount of raw materials used to fulfill the demand of items. One way that can be done to minimize the use of raw materials is to determine the proper cutting, or in the field of Optimization known as Cutting Stock Problem (CSP).

There are many types of CSP, one-dimensional CSP, two-dimensional CSP, and three-dimensional CSP. Dimension size is determined by the side of the remaining cuts (trim loss). The CSP faced by the paper industry in this study was a two dimensional CSP, which in the stock cutting process focused on the long and wide sides.

Previous research on CSP has been widely practiced. Column generation technique (CGT) can be used in the completion of two-dimensional CSP with guillotine-cutting type and fixed orientation, integer solutions obtained by rounding down on the optimal solution [10]. The completion of two-dimensional 2-stage CSP using the Branch and Price and Gomory Cutting Plane methods has also been done previously [2] by adding Gomory Cutting Plane to linear programming relaxation. Then Mrad [9] has used the Branch and Price method to solve two-dimensional CSP models of type guillotine.

The effective cutting methods can be done by cutting paper from one side to the other side of the line or commonly called guillotine cutting [4-6]. Then Mellouli and Damak [8] implemented an algorithm for determining the cutting pattern called pattern generation (PG) algorithm [12] on multiple two-dimensional CSP using CGT. The application of PG algorithm in arc-flow model can facilitate the



search of cutting patterns [1] in one dimensional CSP. For two-dimensional CSP, Octarina et al. [11] created an application for finding the cutting pattern based on the Modified Branch and Bound Algorithm.

Based on this background, this research used PG algorithm in forming Gilmore and Gomory model on two dimensional CSP. The model is extended from the CGT approach proposed by Gilmore and Gomory on a one dimensional CSP. The Gilmore and Gomory model is used to complete two-dimensional CSP on type guillotine and the optimal solution obtained by Branch and Cut method.

2. Research method

Steps conducted in this research are as follows.

1. Determine the data include products name, length and width, and also the demand.
2. Group the data that will be implemented on the PG algorithm in decreasing order.
3. Implement the PG algorithm on two-dimensional CSP to obtain the first cutting pattern and the second cutting pattern.
4. Create a searching tree by using the PG algorithm.
5. Form the cutting pattern table along with cut loss which is depicted from the search tree sequentially by branch.
6. Implement the first and second stage cutting patterns into Gilmore and Gomory models by:
 - a. Defines the variables used.
 - b. Determine the objective function that produces the minimum stock quantity to meet the demand of each item.
 - c. Determine the constraints that ensure strip produced in the first stage is the strips used in the second stage, and will be cut into the requested items. Next define the constraints that ensure all requests item are met.
7. Find the Gilmore and Gomory model solution using the Branch and Cut method and use the LINDO 6.1 program in completing the relaxation LP model.
8. Conclude and obtain the optimal solution.

3. Pattern Generation Algorithm

Let the stock with standard width w'_k and length l'_k , ($k = 1, 2, \dots, h$) will be cut to n items with the width w_i and length l_i ($i = 1, 2, \dots, n$). The model of Cutting Stock Problem can be seen in (1).

$$\text{Minimize } z = \sum_{k=1}^h \sum_{j=1}^{m_k} c_{jk} x_{jk} + \sum_{i=1}^n w_i s_i \quad (1)$$

Subject to:

$$\sum_{k=1}^h \sum_{j=1}^{m_k} a_{ijk} x_{jk} - s_i = l_i \quad \text{for all } i, \quad (2)$$

$$x_{jk}, c_{jk}, s_i, a_{ijk} \geq 0 \quad \text{for all } i, j, k, \quad (3)$$

whereas

a_{ijk} is the number of item with width w_i which cut according to j^{th} cutting pattern from k^{th} stock ($i = 1, 2, \dots, n; j = 1, 2, \dots, m; k = 1, 2, \dots, h$).

x_{jk} is the length of k^{th} stock which cut according to j^{th} cutting pattern.

c_{jk} is the trim loss from k^{th} stock which cut according to j^{th} cutting pattern.

s_i is the remaining length which will produce item with width w_i .

A search tree is used to generate the feasible cutting patterns. The level of the tree represents the required width, which is arranged in decreasing order, the largest size is in the first level while the smallest size is placed at the last level of the tree. The initial vertex from first level is the standard width w'_k which use to generate the cutting pattern.

The branch from i^{th} level of search tree is the multiplication of the number of item and width w_i which represent the number of width item from k^{th} stock to meet w_i width. Vertex from 2^{nd} level to n^{th} is the remaining width after fulfil the certain cutting pattern from the last $i - 1$ branch. The last vertex from search tree is the trim loss from different cutting pattern. Search tree was built from up to down and left to right.

The steps for Pattern Generation (PG) algorithms are as follows:

1. Set the width size $w_i (i = 1, 2, \dots, n)$ in decreasing order.

2. Use $a_{ilk} = \left\lfloor \frac{w'_k - \sum_{z=1}^{i-1} a_{zlk} w_z}{w_i} \right\rfloor$ to fill the first column ($j = 1$) in matrix.

3. Use $c_{jk} = w'_k - \sum_{i=1}^n a_{ijk} w_i$ to find the trim loss from each cutting pattern.

4. Set the level index (row index) i to $n - 1$.

5. Check the vertex in i^{th} level, e.g. vertex (i, j) . If the vertex has the value equals to zero

($a_{ijk} = 0$), go to Step 7. If not, generate the new column $j = j + 1$ with the following elements:

- a. $a_{zjk} = a_{z(j-1)k}$ ($z = 1, 2, \dots, i - 1$) are elements to fill the vertex which precedes vertex (i, j) .
- b. $a_{ijk} = a_{i(j-1)k} - 1$ are elements to fill vertex (i, j) .
- c. Fill the remaining vertex from j column. For example, $a_{(i+1)jk}, a_{(i+2)jk}, \dots, a_{njk}$ using

$$a_{ijk} = \left\lfloor \frac{w'_k - \sum_{z=1}^{i-1} a_{zjk} w_z}{w_i} \right\rfloor$$

6. Use $c_{jk} = w'_k - \sum_{i=1}^n a_{ijk} w_i$ to find cut loss from the j^{th} cutting pattern. Go back to Step 4.

7. Set $i = i - 1$. If $i > 0$, repeat Step 5. Otherwise stop the iteration.

4. Result and Analysis

This section discusses the two dimensional CSP by using the same data from [11]. The name, size and number of each product can be seen in Table 1. The stock has the length and width with the size is 1,090 mm and 970 mm respectively.

Table 1. Products size and demand

No	Product Name (Item)	Length (mm)	Width (mm)	Number of order (pieces)
1	Invitation	325	225	300
2	Business Card	90	60	1,000
3	Pamphlets	210	150	3,000
4	Yasin/Book	230	160	500

PG algorithm was applied to find the cutting patterns. The cutting patterns corresponding to the width and length can be seen in Table 2 and 3 respectively.

Then all the cutting patterns are formed to Gilmore and Gomory model that can be seen in (4).

$$\text{Minimize } z = \lambda_1^0 + \lambda_2^0 + \lambda_3^0 + \lambda_4^0 + \lambda_5^0 + \lambda_6^0 + \lambda_7^0$$

with constraints:

$$\lambda_2^0 + 2\lambda_3^0 + 7\lambda_5^0 + 5\lambda_6^0 + 12\lambda_7^0 - \lambda_1^1 = 0$$

$$\lambda_1^0 + \lambda_2^0 + \lambda_3^0 + 3\lambda_4^0 + 3\lambda_6^0 - \lambda_1^2 - \lambda_2^2 - \lambda_3^2 = 0$$

$$\lambda_1^0 + 2\lambda_2^0 + 3\lambda_3^0 + 2\lambda_4^0 + 2\lambda_5^0 - \lambda_1^3 - \lambda_2^3 - \lambda_3^3 - \lambda_4^3 - \lambda_5^3 - \lambda_6^3 - \lambda_7^3 = 0$$

$$2\lambda_1^0 + \lambda_2^0 - \lambda_1^4 - \lambda_2^4 - \lambda_3^4 - \lambda_4^4 - \lambda_5^4 - \lambda_6^4 - \lambda_7^4 = 0$$

(4)

$$16\lambda_1^1 + 11\lambda_1^2 + 6\lambda_2^2 + \lambda_3^2 + 11\lambda_1^3 + 6\lambda_2^3 + \lambda_3^3 + 8\lambda_4^3 + 3\lambda_5^3 + 3\lambda_6^3 + 7\lambda_1^4 + 2\lambda_2^4 + 6\lambda_3^4 + \lambda_4^4 + 6\lambda_5^4 + \lambda_6^4 + \lambda_7^4 \geq 1.000$$

$$2\lambda_1^2 + 4\lambda_2^2 + 6\lambda_3^2 + \lambda_1^3 + 3\lambda_2^3 + 5\lambda_3^3 + 2\lambda_5^3 + \lambda_6^3 + 2\lambda_2^4 + \lambda_3^4 + 3\lambda_4^4 + 2\lambda_6^4 \geq 3.000$$

$$\lambda_1^3 + \lambda_2^3 + \lambda_3^3 + 3\lambda_4^3 + 3\lambda_5^3 + 4\lambda_6^3 + 6\lambda_7^3 + 2\lambda_1^4 + 2\lambda_2^4 + \lambda_5^4 + \lambda_6^4 \geq 500$$

$$\lambda_1^4 + \lambda_2^4 + 2\lambda_3^4 + 2\lambda_4^4 + 2\lambda_5^4 + 2\lambda_6^4 + 4\lambda_7^4 \geq 300$$

$$\bar{\lambda} \geq 0 \text{ and integer}$$

$$\text{with } \bar{\lambda} = (\lambda_1^0, \dots, \lambda_j^0, \lambda_1^1, \dots, \lambda_j^1, \lambda_1^2, \dots, \lambda_j^2, \dots, \lambda_1^{m'}, \dots, \lambda_j^{m'})^T$$

Table 2. Cutting patterns corresponding to the width

The j^{th} pattern	Number of items				Cut Loss (mm)
	225 mm	160 mm	150 mm	60 mm	
1	4	0	0	1	10
2	2	1	2	1	0
3	2	1	0	6	0
4	2	0	3	1	10
5	2	0	1	6	10
6	1	2	2	2	5
7	1	2	0	7	5
8	0	6	0	0	10
9	0	4	1	3	0
10	0	3	2	3	10
11	0	3	0	8	10
12	0	1	5	1	0
13	0	1	3	6	0
14	0	1	1	11	0
15	0	0	6	1	10
16	0	0	4	6	10
17	0	0	2	11	10
18	0	0	0	16	10

Table 3. Cutting patterns corresponding to the length

The j^{th} pattern	Number of items				Cut Loss (mm)
	325 mm	230 mm	210 mm	90 mm	
1	2	1	1	0	0
2	1	2	1	1	5
3	0	3	1	2	10
4	0	2	3	0	0
5	0	2	0	7	0
6	0	0	3	5	10
7	0	0	0	12	10

Next the model in (4) can be rewritten in Table 4. Optimal solution of Gilmore and Gomory model showed the value of $z = 142$ with $\lambda_1^0 = 38$, $\lambda_4^0 = 99$, $\lambda_6^0 = 5$, $\lambda_1^1 = 25$, $\lambda_2^1 = 3$, $\lambda_3^1 = 347$, $\lambda_3^3 = 182$, $\lambda_4^3 = 1$, $\lambda_7^3 = 53$, $\lambda_3^4 = 2$, and $\lambda_7^4 = 74$. It means the 1st, 4th, and 6th cutting patterns can be used in the first stage, whereas the cutting patterns that can be used in the second stage are as follows.

1. The 1st cutting pattern will be used in the strip with length of 90 mm.
2. The 1st and 3rd cutting patterns will be used in the strip with length of 210 mm.
3. The 3rd, 4th, and 7th cutting patterns will be used in the strip with length of 230 mm, and
4. The 3rd and 7th cutting patterns will be used in the strip with length of 325 mm.

Table 4. Gilmore and Gomory Model

(i, w_i)	λ_0^0	λ_3^0	λ_4^0	λ_5^0	λ_6^0	λ_7^0	λ_1^1	λ_2^1	λ_3^1	λ_3^2	λ_3^3	λ_4^3	λ_3^3	λ_6^3	λ_7^3	λ_1^4	λ_2^4	λ_3^4	λ_4^4	λ_5^4	λ_6^4	λ_7^4		
(90, 60)	0	1	2	0	7	5	12	-1															= 0	
(210, 150)	1	1	1	3	0	3	0																= 0	
(230, 160)	1	2	3	2	2	0	0																= 0	
(325, 225)	2	1	0	0	0	0	0																= 0	
(90, 60)							16	11	6	1	11	6	1	8	3	3	0	7	2	6	1	6	1	$\geq 1,000$
(210, 150)							0	2	4	6	1	3	5	0	2	1	0	0	2	1	3	0	2	$\geq 3,000$
(230, 160)							0	0	0	0	1	1	1	3	3	4	6	2	2	0	0	1	1	≥ 500
(325, 225)							0	0	0	0	0	0	0	0	0	0	0	1	1	2	2	2	2	≥ 300
Objective function	1	1	1	1	1	1	1																	

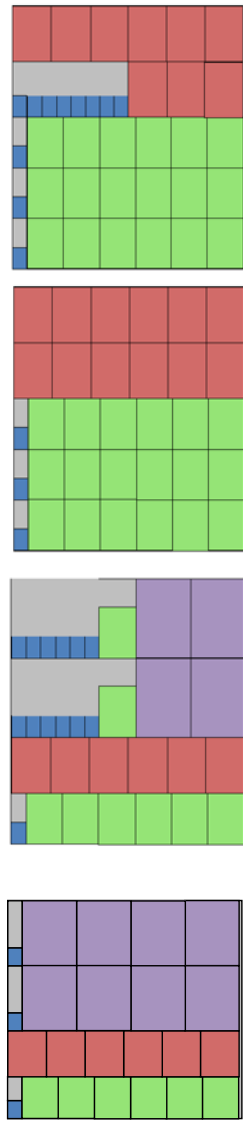


Figure 1. First Combination
Figure 2. Second Combination
Figure 3. Third Combination
Figure 4. Fourth Combination

Based on the implementation of pattern generation algorithm on cutting pattern determination, it found 57 cutting patterns corresponding to the width and 34 cutting patterns corresponding to the length. The cutting pattern chosen is the pattern that has the minimum cut loss and at the same time can meet the availability of items ordered, so the selected pattern is a pattern with a cut loss of no more than 10 millimeters as many as 18 cutting patterns corresponding to the width and 7 cutting patterns according to the length.

The selected cutting patterns, formed into the Gilmore and Gomory model and completed using Branch and Cut method and LINDO 6.1 program. The addition of Gomory restrictions in this study did not adequately affect the solution obtained due to the large number of variables. The number of items resulting from stock cuts are 142 sheets based on the optimal cutting pattern. The optimal solution obtained is substituted into Gilmore and Gomory model constraints, resulting in 1,056 sheets of business cards, 3,000 pamphlets, 503 pieces of Yasin / books, and 300 pieces of invitations. Each item produced is not less than the request, the resulting excess amount can be used for the next order.

The optimal solution from the first and second stage can be combined to the new cutting patterns, as shown in Figures 1-7.

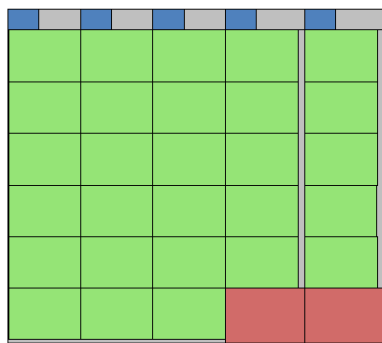



Figure 5. Fifth Combination

Note:  means trim loss



means business card

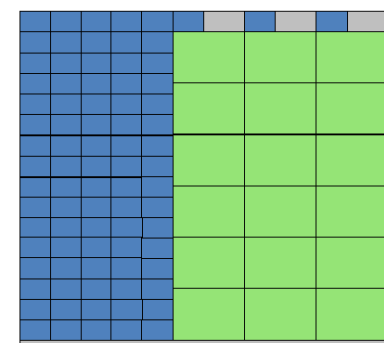



Figure 6. Sixth Combination

 means pamphlets



means Yasin/books

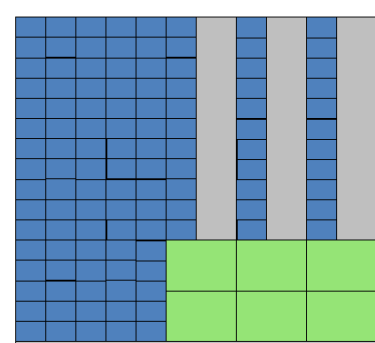



Figure 7. Seventh Combination

 means invitations

Figures 1-7, shows that there are 7 combinations of cutting patterns that can be used. Trim loss from each cutting patterns can be used again to produce the other items that fixed the size.

5. Conclusion

From the result, it can be concluded that implementation of PG algorithm helps the searching of cutting patterns become easier. Then, the patterns can be modelled as Gilmore and Gomory model whereas the objective function is to minimize the number of cutting stock and the constraints assure that the strips from first stage can be reused in the second stage in order to meet all the demands.

Acknowledgement

The research leading to this study was financially supported by Directorate of Higher Education Indonesia (DIKTI) for support through “Penelitian Produk Terapan”, 2017.

References

- [1] Bangun P B J, Octarina S, and Apriani R 2016 Penyelesaian algoritma *pattern generation* dengan model *arc-flow* pada *cutting stock problem* (CSP) satu dimensi *Proceeding Annual Research Seminar* Fakultas Ilmu Komputer Universitas Sriwijaya
- [2] Belov G and Scheithauer G 2004 A branch and cut and price algorithm for one dimensional stock cutting and two dimensional two stage cutting *European Journal of Operational Research* **171**(1) 85-106
- [3] Chen D S, Batson R G, and Dang Y 2010 *Applied Integer Programming Modeling and Solution* (New Jersey: John Wiley & Sons)
- [4] Gilmore P and Gomory R 1961 A linear programming approach to the cutting stock problem *Operations Research* **9**(6) 849 - 859
- [5] Gilmore P and Gomory R 1963 A linear programming approach to the cutting stock problem II *Operations Research* **11**(6) 863 - 888

- [6] Gilmore P and Gomory R 1965 Multistage cutting stock problems of two and more dimension *Operations Research* **13**(1): 94 – 120
- [7] Macedo R A S G 2011 Models and algorithms for hard optimization problems *Thesis* Universidade do Minho Braga
- [8] Mellouli A and Dammak A 2008 An algorithm for the two dimensional cutting stock problem based on a pattern generation procedure *Information and Management Science* **19**(2): 201 – 218
- [9] Mrad M, Meftahi I, and Haouari M 2012 A branch-and-price algorithm for the two stage guillotine cutting stock problem *Journal of the Operational Research Society*, 1-9
- [10] Novianingsih K, Hadiani R, and Uttunggadewa S 2007 Column generation technique for solving two dimensional cutting stock problems: method of stripe approach *Journal of The Indonesian Mathematical Society (MIHMI)* **13**(2), 161-172
- [11] Octarina S, Bangun P B J, and Hutapea S 2016 The application to find cutting pattern in two dimensional cutting stock problem *Accepted and to be published in Journal of Informatics and Mathematical Science*
- [12] Suliman S M A 2001 Pattern generating procedure for the cutting stock problem *International Journal of Production Economics*, **74** : 293-301