Institut
Teknologi
Sepuluh Nopember

PROCEEDINGS

6TH INTERNATIONAL CONFERENCE ON OPERATIONS AND SUPPLY CHAIN MANAGEMENT (OSCM)

"Making the world more comfortable, sustainable, and socially responsible: the role of operations and supply chain management."

Sanur Paradise Plaza Hotel, Bali
10-12 December 2014

Organized by:

Industrial Engineering Departement
Faculty of Industrial Technology
Sepuluh Nopember Institute of Technology

Organized by: Laboratory of Logistics and Supply Chain Management, Industrial Engineering Department, Institut Teknologi Sepuluh Nopember (ITS) Surabaya - Indonesia

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Edited by:
I Nyoman Pujawan
Iwan Vanany
Imam Baihaqi

CONTENT

WELCOME SPEECH FROM CONFERENCE CHAIR

Welcome to the sixth International Conference on Operations and Supply Chain Management. As you all know, this year conference brings a very important theme “Making the world more comfortable, sustainable, and socially responsible: the role of operations and supply chain management “. It is this theme that motivates us to work and contribute to the world. Operations and Supply Chain Management has always been aimed toward better processes, better working environments, more efficient use of resources, more respect toward human life as well as the environment.

This conference is the continuation of the five earlier conferences which were held in Bali (2005), Bangkok (2007), Malaysia (2009), Maldives (2011), and India (2013). This year we are able to attract submissions of more than 200 abstracts from about 35 countries. We did the review in two stages: abstract submission and full paper submission. The number of papers scheduled for presentation is 124 which represent authors from 28 countries. In addition, we also have three keynote speaker sessions and one workshop for young academics and doctoral students. Also, this is the first time we run a forum for PhD program director / coordinator. We are very proud with the quality of submissions and the internationalization of the conference. It is also our aim to enhance the OSCM Forum with the formation of Board Members. The Board Members will set the direction of the forum, give suggestions for organization of future conferences, and supporting the publication of the associated journal “Operations and Supply Chain Management” which is now in its 7th year. It is also our first time giving awards to best reviewers and best papers. Without neglecting the roles of other reviewers and other authors, our aim is to give appreciation to excellent works and contribution of the conference participants.

Finally, I would like to thank all parties that have contributed to this conference. First of all, I would like to thank the three keynote speakers: Professor René B.M. de Koster from Rotterdam School of Management, Erasmus University, The Netherlands; Professor Mahender Singh, the CEO/Rector of Malaysia Institute for Supply Chain Innovation (MISI); and Walter Kuijpers from Deloitte Consulting’s SE Asia. My sincere thanks also goes to Professor Suresh Sethi from University of Texas at Dallas, USA and Professor Yossi Aviv from Olin Business School, Washington University, USA who both will give talks in the workshop for doctoral students and emerging scholars. I would also like to thank the supports and participation of the supporting organizations and sponsors. The support from our institution (Institut Teknologi Sepuluh Nopember) is also instrumental to the success of this conference. Finally, to all committee members I would like to thank for the hard work, without which this conference would never be a success.To all participants, have a nice conference and we look forward to your continuing support to OSCM.

Bali, December 2014

Professor Nyoman Pujawan, Ph.D, CSCP
Conference Chair

WELCOME MESSAGE FROM RECTOR OF ITS SURABAYA

On behalf of the Institut Teknologi Sepuluh Nopember (ITS), I welcome the participants to this year Operations and Supply Chain Management (OSCM) Conference. I am truly proud that the Laboratory of Logistics and Supply Chain Management in the Department of Industrial Engineering has managed to organize such a prestigious conference, attracting delegates from various countries. Being Lab-Based Education, this conference is one of the strategies to achieve our vision as a world class research university.

This year conference theme: "making the world more comfortable, sustainable, and socially responsible: the role of operations and supply chain management" is very timely. This conveys a strong message that all of our activities to improve the companies' performance must also consider the quality our environment and social development as well. I believe, with such diverse and large participation, this conference will serve as an effective platform for academics, practitioners, and students to learn, share, and exchange their expertise and insights, especially on how the operations and supply chain management could contribute to maintain the sustainability of our planet.

I congratulate and thank Prof. Nyoman Pujawan, the conference chair and his team from the Department of Industrial Engineering, who have worked tirelessly to make this OSCM 2014 conference possible.

I sincerely hope that this conference will facilitate the establishment of international joint research programs and become a forum for the exchange of research ideas. I wish the conference a grand success.

Surabaya, December 2014

Professor Dr. Triyogi Yuwono
Rector of ITS

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- Javad Feizabadi, Malaysia Institute for Supply Chain Innovation, Malaysia
- Dimitris Folinas, Alexadrion Technological Educational Institute of Thessaloniki, Greece
- M. Abdul Hoque, University of Brunei Darussalam
- Takashi Irohara, Sophia University, Japan
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- Ruhul Amin Sarker, University of New South Wales, Australia
- Anders Segerstedt, Luleå University of Technology, Sweden
- Togar Simatupang, Bandung Institute of Technology, Indonesia
- Himanshu Shee, Victoria University, Australia
- Harm-Jan Steenhuis, Eastern Washington University, USA
- Katsuhiko Takahashi, Hiroshima University, Japan
- Armagan Tarim, Hacettepe University, Turkey
- Benny Tjahjono, Cranfield University, UK
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SPONSOR PROFILE

Chevron Indonesia

Chevron is one of the world's leading integrated energy companies. Our success is driven by our people and their commitment to get results the right way—by operating responsibly, executing with excellence, applying innovative technologies and capturing new opportunities for profitable growth. We are involved in virtually every facet of the energy industry. We explore for, produce and transport crude oil and natural gas; refine, market and distribute transportation fuels and lubricants; manufacture and sell petrochemical products; generate power and produce geothermal energy; provide renewable energy and energy efficiency solutions; and develop the energy resources of the future, including research into advanced biofuels.

Company Roots: We trace our beginnings to an 1879 oil discovery at Pico Canyon, north of Los Angeles, which led to the formation of the Pacific Coast Oil Co. That company later became Standard Oil Co. of California and, subsequently, Chevron. We took on the name Chevron when we acquired Gulf Oil Corporation in 1984, which nearly doubled our worldwide proved crude oil and natural gas reserves. Our merger with Gulf was then the largest in U.S. history.Another major branch of the family tree is The Texas Fuel Company, formed in Beaumont, Texas, in 1901. It later became known as The Texas Company and, eventually, Texaco. In 2001, our two companies merged. The acquisition of Unocal Corporation in 2005 strengthened Chevron's position as an energy industry leader, increasing our crude oil and natural gas assets around the world.

Global Scope: Our diverse and highly skilled global workforce consists of approximately 64,500 employees, including more than 3,200 service station employees.
In 2013, Chevron's average net production was nearly 2.6 million oil-equivalent barrels per day. About 75 percent of that production occurred outside the United States. Chevron had a global refining capacity of 1.96 million barrels of oil per day at the end of 2013.
Our marketing network supports retail outlets on five continents.

Technology and Emerging Energy : We focus on technologies that improve our ability to find, develop and produce crude oil and natural gas from conventional and unconventional resources.We also invest in the development of emerging energy technologies, such as finding better ways to make nonfood-based biofuels, piloting advanced solar technology for our operations and expanding our renewable energy resources.

Environment and Safety: As a company and as individuals, we take great pride in contributing to the communities where we live and work.We also care about the environment and are proud of the many ways in which our employees work to safeguard it.Our persistent efforts to improve on our safe work environment continue to pay off. In 2013, we achieved world-class performance in the days-away-from-work metric for both Upstream and Downstream operations.

Our Work: We recognize that the world needs all the energy we can develop, in every potential form. That's why our employees work to responsibly develop the affordable, reliable energy the world needs.

PT. Semen Indonesia (Persero) Tbk.

The Company inaugurated in Gresik on December 7 Agustus1957 by the first President with an installed capacity of 250,000 tonnes of cement per year, and installed capacity in 2013 reach 30 million tons/year. On July 8, 1991 the Company's shares listed on the Jakarta Stock Exchange and Surabaya Stock Exchange (now Indonesia Stock Exchange) and is the first state-owned companies to go public by selling 40 million shares to the public. The composition of the shareholders at the time: State of RI 73% and 27% people.In September 1995, the Company made a Rights Issue I (Right Issue I), which alter the composition of share ownership to the State of RI 65% and 35% people. On June 15 September 1995 by PT Semen Gresik consolidate with PT Semen Padang and PT Semen Tonasa. Total installed capacity of the Company at the time of 8.5 million tons of cement per year.On September 17, 1998, the State of RI off its stake in the Company by 14% through an open offer, which was won by CEMEX S. A. de C. V., a global cement company based in Mexico. Shareholding composition changed to Republic of Indonesia 51%, the 35%, 14% and Cemex. Then on 30 September 1999 shareholding changed to: The Government of the Republic of Indonesia 51.0%, 23.4% and the 25.5% Cemex.On July 27, 2006, there was the sale of shares of Cemex Asia Holdings Ltd. to Blue Valley Holdings PTE Ltd. so the shareholding composition changed to 51.0% RI State Blue Valley Holdings PTE Ltd.. 24.9%, 24.0%, and the community. In late March 2010, Blue Valley Holdings PTELtd, sold all of its shares through a private placement, so the composition of the shareholders of the Company changed to 51.0% Government 48.9% and the public.Dated December 18, 2012 was a historic moment when the Company signed a final transaction acquisition of 70 percent stake in Thang Long Cement, the leading cement companies of Vietnam has a production capacity of 2.3 million tons / year. Acquisition of Thang Long Cement Company is also to make the Company's status as the first state-owned multi-national corporation. Has established its position as the largest cement producer in Southeast Asia with a capacity up to the year 2013 amounted to 30 million tonnes per year.

- Complete the construction of a cement factory unit
- The acquisition of Thang Long Cement Joint stock Company (TLCC), in Viet Nam.
- Became Strategic Holding Company and changed its name to PT Cement Indonesia (Persero) Tbk.

Transformation of the Company as an effort to improve the performance, after the application of Functional Holding through synergy of their respective companies' competence both in operational and marketing field. Improve the quality of management of the Company's organization and conduct more intensive communication with stakeholders in each operating company.

Total E&P Indonesie

Energy is vital to economic development and improved standards of living. Wherever it is available, energy is helping to drive progress, but sustainability requires changes in the way that it is used and managed. This conviction shapes everything we do. With operations in more than 130 countries, we are a top-tier international oil company and a world-class natural gas operator, refiner, petrochemical producer, and fuel and lubricant retailer. Our 100,000 employees leverage their globally acknowledged expertise so that together they can discover, produce, refine and distribute oil and gas to provide products and services for customers worldwide. We are also developing energies that can partner oil and gas — today, solar energy and tomorrow, biomass. As a responsible corporate citizen, we focus on ensuring that our operations consistently deliver economic, social and environmental benefits.

A Market Leader in Our Areas of Expertise

Exploration & Production is responsible for our oil and natural gas exploration, development and production activities in more than 50 countries.**Gas& Power** unlocks the value of our natural gas assets. Its capabilities span the liquefied natural gas chain, from liquefaction to shipping and regasification, as well as natural gas marketing. **Refining & Chemicals** is a major production hub, with expertise covering refining, petrochemicals and specialty chemicals. We rank as one of the world's ten largest integrated producers. **Trading & Shipping** sells our crude oil production, supplies our refineries with feedstock, charters the vessels required for those activities and is involved in derivatives trading. We are a leading global trader of oil and petroleum products.**Marketing & Services** designs and markets a broad array of refined products, including automotive fuel and specialty products such as LPG, heating and heavy fuel oil, asphalt, lubricants and special fluids. It also provides services to consumers and to the transportation, housing and manufacturing industries. We are a leading marketer in Western Europe[4] and the top marketer in Africa.[4]

New Energies is helping us to prepare the energy future by developing our expertise in two core renewable energies, solar and biomass

INDUSTRIAL ENGINEERING ITS

Department of Industrial Engineering (IE-ITS) as one of the biggest departments in ITS stand as study program in 1985. IE-ITS has been successful in its efforts to develop its education programs, this is reflected in the accreditation gained since 1999 to the present (A). Number of alumni is more than 1000 people spread across various sectors of national and international industry, and the number of new students is about 200 people per year, supported by qualified teaching staff and have high competence and qualifications in their respective fields. IT-ITS to be one of the best industrial engineering department in Indonesia has more than 30 faculty members with diverse areas of expertise such as ergonomics, system manufacturing, sustainable manufacturing, optimization, simulation, data mining, logistics, supply chain, quality management and performance measurement makes the Department of Industrial Engineering (IE-ITS) as the primary barometer of "Industrial Engineering" in Indonesia. ITS open undergraduate (S1) and graduate (S2 and S3) programs. The programs are also open to international students delivered in English. Some college participants both undergraduate and graduate are from various countries such as Iraq, Zimbabwe, Papua New Guinea, Thailand and Myanmar.

Vision

IE-ITS aims to be an institution of higher education in Industrial Engineering with excellent international reputation and capable of supporting sustainable national development.

Mission

- To implement educational programs and research activities in the field of Industrial Engineering with international reputation.
- To provide services relevant to the needs of industry and communities to support sustainable national development.
- To build a cooperation network for development of educational and research activities to empower human resources and all resources owned.
- To conduct research and development in the field of science and Industrial Engineering with quality and contribution to the advancement of science and technology.

Purposes

- To produce qualified graduates of Industrial Engineering relevant to the needs of industry and community and develop activities of designing, engineering, improvement, and installation.
- To produce research and development in scientific fields of Industrial Engineering with quality and contribution to the advancement of science and technology.
- To apply the concepts, methods and techniques of research results within the professional scope of Industrial Engineering.

Program Education Objectives

1. To be able to formulate problem in industrial system, either micro, mezzo or macro level, to propose alternative solutions
2. To comprehend and innovatively perform theoretical improvement in Industrial Engineering discipline by focusing on system approach to design, improve and install an integrated system
3. To be able to manage research and development activities in industrial engineering discipline based on academic norms fairly and responsibly and to be able to communicate ideas and research results effectively both in Bahasa Indonesia and English in order to achieve national and international recognition.
4. To poses professional attitude and conduct as an individual and/or a team member in working environment
5. To be able manage his/herself and to behave professionally in working environment
6. To be able to cooperate in team proportionally in accordance to working demand.
7. To be able to communicate ideas systematically, both oral and written in Bahasa Indonesia or English.
8. To have sensitivity to environmental and sustainability issues and to accommodate those issues in performing analysis, design, dan decision making.
9. To be able to be creative and innovative in some aspects of living, especially to those with relation to his/her profession.

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Operations and Supply Chain Management: An International Journal (**OSCM**) publishes high quality refereed articles in the field of operations and supply chain management. The journal invites original contributions that present modeling, empirical, review, and conceptual works. To enable maximum dissemination, the articles are freely accessible through the internet to anybody and a limited printed version will be available at cost.

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Submission of Manuscripts
All manuscript should be submitted to the journal editor electronically in an MS word file to the Editor-in-Chief at: **oscm.editor@gmail.com**.

KEYNOTE SPEAKER

Keynote Speech I: **Professor Dr. René B.M. de Koster, Rotterdam School of Management, Erasmus University, The Netherlands. "The impact of behavior on operational performance".**

Dr. René B.M. de Koster is professor of Logistics and Operations Management at Rotterdam School of Management, Erasmus University since 1995. Before that, he worked as a consultant. His research interests are warehousing, container terminal, retail, and behavioural operations. He is author/editor of 8 books and over 130 papers in books and journals like Production and Operations Management, Journal of Operations Management, Transportation Science, IIE Transactions, European Journal of Operational Research. He is in the editorial boards of journals like OR, JOM, TS (SI editor), IJOPM (SI editor) and other academic journals, member of several international research advisory boards (ELA: European Logistics Association, BVL, AIRL, University of Pisa, chairman of Stichting Logistica, Smartport, and founder of the Material Handling Forum. His research has won several awards, like the IIE Transactions best paper award (2009), JOM best paper finalist (2007), AoM best paper finalist (2013), ERIM impact award (2013).

Keynote Speech II: **Walter Kuijpers**, **Deloitte Consulting's SE Asia "Journey to supply chain reengineering – opportunities and challenges"**

Walter is a Senior Manager at Deloitte Consulting South East Asia responsible for Supply Chain Management within the Strategy & Operations service line. He earned his BSc. Engineering Degree in Analytical Chemistry from the Dutch Hanzehogeschool in Groningen (Netherlands) followed by a Post-Academic Degree in Distribution Logistics. He has over 15 years' experience with a balanced mix of consulting and industry experience in Supply Chain Management covering Inventory Management, Collaborative Planning & Forecasting, Logistics Operations, and Sales & Distribution. He has worked across Consumer Business, Hi-Tech, Telecommunications and Energy & Resources industries in supply chain project delivery, sales and P&L roles across Europe, Australia, Japan,India, China and South East Asia.

Keynote speech III: **Professor Dr. Mahender Singh, CEO/Rector of Malaysia Institute for Supply Chain Innovation (MISI)**

Dr. Mahender Singh is the CEO/Rector of the newly launched Malaysia Institute for Supply Chain Innovation (MISI) since its inception in March 2011. MISI is a joint initiative between the Massachusetts Institute of Technology, USA (MIT) and the Government of Malaysia – www.misi.edu.my. He also holds the position of the Executive Director of the MIT Global SCALE Network in Asia at the Center for Transportation and Logistics at MIT, where he has been working for the past 10 years. Dr. Singh has over 18 years of experience in the field of supply chain management. Before returning to academia in 2003, he worked with a leading consulting firm to implement innovative global supply chain planning solution for Fortune 50 companies. He has spent considerable time in various countries working on supply chain challenges. Dr. Singh's research and teaching is focused on operations and supply chain management, with particular interest in exploring the underlying structure of complex supply chains. His current research efforts span the domain of supply chain strategy, risk management and healthcare supply chains.His research has been published in leading academic journals such as Management Science and IIE Transactions, as well as Sloan Management Review and Supply Chain Management Review. Dr. Singh has an Undergraduate degree with Honors in Physics. He earned his Masters degree in Logistics from MIT and received his Ph.D. in Management Science from the University of Tennessee, Knoxville. In addition, he has a Masters degree in Statistics and is a certified Cost Accountant.

WORKSHOP FOR DOCTORAL AND EMERGING SCHOLARS

Speaker I: **Professor Dr. Suresh Sethi, University of Texas at Dallas, USA**

Suresh P. Sethi is Eugene McDermott Professor of Operations Management and Director of the Center for Intelligent Supply Networks at The University of Texas at Dallas. He has written 7 books and published nearly 400 research papers in the fields of manufacturing and operations management, finance and economics, marketing, and optimization theory. He teaches a course on optimal control theory/applications and organizes a seminar series on operations management topics. He initiated and developed the doctoral programs in operations management at both University of Texas at Dallas and University of Toronto. He serves on the editorial boards of several journals including Production and Operations Management and SIAM Journal on Control and Optimization. He was named a Fellow of The Royal Society of Canada in 1994. Two conferences were organized and two books edited in his honor in 2005-6. Other honors include: IEEE Fellow (2001), INFORMS Fellow (2003), AAAS Fellow (2003), POMS Fellow (2005), IITB Distinguished Alum (2008), SIAM Fellow (2009), POMS President (2012).

Speaker II: **Professor Dr. Yossi Aviv, Olin Business School, Washington University, USA**

Professor Aviv,Dan Broida Professor of Operations & Manufacturing Management, develops and applies operations research models and methods to study problems related to supply chain management and revenue management. His current research focuses on strategic inventory positioning in distribution networks, collaborative forecasting, and dynamic pricing. He holds several editorial positions, and serves as a Department Editor (Area of Operations Management) for Management Science, the flagship journal in his field. Aviv has consulted in the defense and electronics industries. At the Olin School of Business, he has been teaching courses on quantitative decision modeling, operations management, and supply chain management, at the undergraduate, MBA, PMBA, EMBA, and Ph.D. levels.

LIST OF PARTISIPANT

Name	Institution	Country
Achmad Room Fitrianto	The State Islamic Univeristy of Sunan Ampel	Indonesia
Adewole Akanni	Gillette UK Ltd	United Kingdom
Adi Budipriyanto	Sepuluh Nopember Institute of Technology	Indonesia
Agustina Eunike	Brawijaya University	Indonesia
Ahmad Abareshi	RMIT University	Australia
Ahmad Jafarnejad	University of Tehran	Iran
Ahmad Rusdiansyah	Sepuluh Nopember Institute of Technology	Indonesia
Alan Chee Wee Tay	School of Business, SIM University	Singapore
Alan Teik Cheng Lim	School of Science and Technology, SIM University	Singapore
Alassane Ballé Ndiaye	Université Libre de Bruxelles	Belgium
Alexis Nsamzinshuti	Université Libre de Bruxelles	Belgium
Amak Mohamad Yaqoub	Airlangga University	Indonesia
Amal S. Kumarage	University of Moratuwa	Sri Lanka
Andhy Hermawan	Monash University	Australia
Andi Cakravastia	Bandung Institute of Technology	Indonesia
Andre R Daud	Padjajaran University	Indonesia
Andreas C. Soteriou	University of Cyprus	Cyprus
Andries Stam	Erasmus University	Netherlands
Andrzej Rzeczycki	University of Szczecin	Poland
Anggriani Profita	Mulawarman University	Indonesia
Anna-Mara Schön	University of Applied Sciences Fulda	Germany
Anny Maryani	Sepuluh Nopember Institute of Technology	Indonesia
Antti Salminen	Lappeenranta University of Technology	Finland
Anup Pradhan	University of Johannesburg	South Africa
Asep Ridwan	Universitat Duisburg-Essen	Germany
Attila Turi	Politehnica University from Timisoara	Romania
Bartholomeus Tandigala	Indonesian Local Board for Disaster Management in Central Sulawesi Province	Indonesia
Basuki Widodo	Sepuluh Nopember Institute of Technology	Indonesia
Benny Tjahjono	School of Management, Cranfield University	United Kingdom
Bernd Noche	Duisburg-Essen University	Germany
Bin Dan	Chongqing University	China
Blanka Tundys	University of Szczecin	Poland
Blen Delelegne	Narvik University College	Norway
Bruno de Sousa Alves	Federal University of Santa Carina	Brazil
Budi Santosa	Sepuluh Nopember Institute of Technology	Indonesia
Budisantoso Wirjodirdjo	Sepuluh Nopember Institute of Technology	Indonesia
Bustanul Arifin	Sepuluh Nopember Institute of Technology	Indonesia
Candra Bachtiyar	National Taiwan University of Science and Technology	Taiwan

Carles Sitompul	Parahyangan Catholic University	Indonesia
Carlos Ernani Fries	Federal University of Santa Carina	Brazil
Charles Mbohwa	University of Johannesburg	South Africa
Charoenchai Khompatraporn	King Mongkut’s University of Technology Thonburi	Thailand
Chi-Leung Chu	National Chiayi University	Taiwan
Christakis Charalambous	University of Cyprus	Cyprus
Dalvio Ferrari Tubino	Federal University of Santa Carina	Brazil
Danang Setiawan	Sepuluh Nopember Institute of Technology	Indonesia
Dewanti Anggrahini	Sepuluh Nopember Institute of Technology	Indonesia
Dewie Saktia Ardiantono	Sepuluh Nopember Institute of Technology	Indonesia
Didik Wahjudi	Petra Christian University	Indonesia
Dina Natalia Prayogo	University of Surabaya	Indonesia
Dino Rimantho	Pancasila University	Indonesia
Dmitry Krass	Canada University of Toronto	Canada
Dr. Nadeem Ehsan	CASE	Pakistan
Duangpun Kritchanchai	Mahidol University	Thailand
Dwi Agustina	Nanyang Technological University	Singapore
Dwi Purnomo	Padjajaran University	Indonesia
Dyah Santhi Dewi	Sepuluh Nopember Institute of Technology	Indonesia
Eddy Renaldi	Padjajaran University	Indonesia
Effi Latiffianti	Sepuluh Nopember Institute of Technology	Indonesia
Eko Liquiddanu	University of Sebelas Maret	Indonesia
Eko Nurmianto	Sepuluh Nopember Institute of Technology	Indonesia
Elimawaty Rombe	Tadulako University	Indonesia
Ellisha Nasruddin	Universiti Sains Malaysia	Malaysia
Endang Retno Wedowati	Wijaya Kusuma Surabaya University	Indonesia
Eric van Heck	Erasmus University	Netherlands
Erna Mulyati	Sepuluh Nopember Institute of Technology	Indonesia
Erwin Widodo	Sepuluh Nopember Institute of Technology	Indonesia
Eugene-Eu-Chun Lee	Universiti Sains Malaysia	Malaysia
Farzad Bahrami	University of Tehran	Iran
Farzeen Jaswal	University of Greenwich	United Kingdom
Febrianus D. Wibisono	Bandung Institute of Technology	Indonesia
Femi Yulianti	Bandung Institute of Technology	Indonesia
Ferry Jie	RMIT University	Australia
Fikhi Adrian	Bandung Institute of Technology	Indonesia
Fiqihesa Putamawa	Sepuluh Nopember Institute of Technology	Indonesia
Friska Hanna Tarida	Sepuluh Nopember Institute of Technology	Indonesia
Gama Harta Nugraha Nur Rahayu	STIMIK ESQ	Indonesia
Geevaneswary Saththasivam	Universiti Sains Malaysia	Malaysia
George C. Hadjinicola	University of Cyprus	Cyprus

Gilles Goncalves	Univ Lille Nord de France	France
Glauco G. M. P. da Silva	Federal University of Santa Carina	Brazil
Govardhan Rao Banna	School of Business, SIM University	Singapore
Gul Pervez	Concordia University	Canada
Gusti Fauza	University of South Australia, Sebelas Maret University	Australia/Indonesia
Guy Maltais	Université de Sherbrooke	Canada
Haiyue Zhang	Chongqing University	China
Hanim Maria Astuti	Institut Teknologi Sepuluh Nopember	Indonesia
Hari Prasetyo	Universitas Muhammadiyah Surakarta	Indonesia
Hasan Akpolat	University of Technology Sydney	Australia
Heidi Piili	Lappeenranta University of Technology	Finland
Heru Prastawa	Sepuluh Nopember Institute of Technology	Indonesia
Himanshu K. Shee	Victoria University	Australia
I Ketut Gunarta	Sepuluh Nopember Institute of Technology	Indonesia
I Nyoman Pujawan	Sepuluh Nopember Institute of Technology	Indonesia
Ibnu Hisyam	Sepuluh Nopember Institute of Technology	Indonesia
Ignatio Madanhire	University of Johannesburg	South Africa
Ika Sari Wahyuni-TD	International Islamic University Malaysia	Malaysia
Imam Baihaqi	Sepuluh Nopember Institute of Technology	Indonesia
Ioannis Manikas	University of Greenwich	United Kingdom
Ishardita Pambudi Tama	Brawijaya University	Indonesia
Ivan Varela Rozados	Cranfield University	United Kingdom
Iwan Vanany	Sepuluh Nopember Institute of Technology	Indonesia
Javad Fezabadi	Malaysia Institute for Supply Chain Innovation (MISI)	Malaysia
Jianfu Wang	Canada University of Toronto	Canada
Joakim Widstrand	Chalmers University of Technology	Sweden
Joey-Soo-Yee Phuah	Universiti Sains Malaysia	Malaysia
Johannes B. Mapokgole	University of Johannesburg	South Africa
John L. Hopkins	Swinburne University of Technology	Australia
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Judy McKay	Swinburne University of Technology	Australia
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Maria Widyarini	Parahyangan Catholic University	Indonesia
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Sudiyono Kromodihardjo	Sepuluh Nopember Institute of Technology	Indonesia
Sukoyo	Institut Teknologi Bandung	Indonesia
Suparno	Sepuluh Nopember Institute of Technology	Indonesia
Suprayogi	Institut Teknologi Bandung	Indonesia
Surahman Surahman	Victoria University, Politeknik Negeri Samarinda	Australia
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Tuanjai Somboonwiwat	King Mongkut's University of Technology Thonburi	Thailand
Udisubakti Ciptomulyono	Sepuluh Nopember Institute of Technology	Indonesia
Vaibhav Gupta	Indian Institute of Technology	India
Victor Gekara	School of Bussiness IT and Logistics, RMIT	Australia

	University	
Victor Suhandi	Maranatha Christian University	Indonesia
Vincent F. Yu	National Taiwan University of Science and Technology	Taiwan
Vincent Li	Taiwan National Chiayi University	Taiwan
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Waqar Ahmed Mirza	Aga Khan University Hospital	Pakistan
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Winda Narulidea	Sepuluh Nopember Institute of Technology	Indonesia
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Xiuzhou Zhang	Chongqing University	China
Xumei Zhang	Chongqing University	China
Yan Weng Tan	School of Business, SIM University	Singapore
Yanuar Tri Sulistyo	Telkom University	Indonesia
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Yicheng Lin	Taiwan National Chiayi University	Taiwan
Yohei Shinkawa	Waseda University	Japan
Yousef Amer	School of Engineering, University of South Australia	Australia
Yuanita Handayati	Institut Teknologi Bandung	Indonesia
Yudi Fernando	Universiti Sains Malaysia	Malaysia
Yuliani Dwi Lestari	Bandung Institute of Technology	Indonesia

ANALYSIS OF OPTIMALITY AND DEVELOPMENT OF PRIORITY DISPATCHING METHOD TO MINIMIZE TOTAL TARDINESS FOR UNRELATED PARALLEL MACHINES SCHEDULING

Victor Suhandi
Department of Industrial Engineering, Maranatha Christian University,
Bandung 40164 Indonesia, Email: victorsuhandi@yahoo.com

ABSTRACT

Research on jobs scheduling on parallel machines has been very diverse. There are problems in which a job has a different processing time when it was done on a different machine. The problem that arises is the assignment of machine which we choose to do the job and also schedule jobs on machines. The performance measure is total tardiness. We use priority dispatching (PD) method. This method is a heuristic method. This method can handle very large problems and is expected to give good results. This method schedules jobs one by one. Criteria used in selecting a couple of job and the machine which are assigned, respectively, are: jobs that will surely experience tardiness; jobs which have least number of preferences that not to be tardy; least ready time; load of machines that count from the sum of the time of all jobs that still may be done on each machines; and the due date. Assessment results of this method are done by comparing the total tardiness produced by the first come first serve (FCFS) method and generate and test method (G & T). FCFS method is a representation of a very simple method that is frequently used in practice and the results are usually far from optimal. Meanwhile, the G & T method is an enumeration method to generate all combinations and test in order to obtain optimal results, but this method is only able to handle a simple problem. The G & T method uses depth first search (DFS) strategy and combine it with backtracking. If the results of the PD are close to G & T, it means PD method is close to optimal, but instead when they are away from G & T and closer to the FCFS method, it means it is far from optimal. Testing data was conducted by using random numbers for a hypothetical 6 jobs and 3 machines that are still feasible using the G & T. The processing time is generated with random numbers which have uniform (15, 25) and the due date of each job is uniform (30, 50). It is generated to make the possibility of tardiness occurrences. Each machine has to process about 2 jobs so that the due date is given in the range of 2 times of the processing time of each job. The results obtained by the PD method have the optimality closeness of 91.75% (excellent) for the case where each job can be done on all machines. And for the case where each job which cannot be processed on all the machines, it gets the optimality closeness value at 50.42% (less good).

Keywords: scheduling, unrelated parallel machines, priority dispatching, optimality closeness

1. INTRODUCTION

Research in the field of job scheduling has been highly developed today. More specifically, research in the field of scheduling jobs on parallel machines with a variety of criteria to be optimized. E. Mokotoff (1999), applies the optimization of scheduling jobs on parallel machines with makespan minimization criteria so that the models can be developed using Binary Integer

Programming (BIP) are classified as NP-complete. However, scheduling jobs on parallel machines with a total tardiness criterion are still classified as NP-hard.

T. Sen et al. (2003) mapped the scheduling problem with linking to a variety of methods. In his paper, a single machine problem is solved by using Mixed Integer Programming (MIP). In this case, Taha (2007) using MIP solved by AMPL software is able to obtain optimal results for scheduling on a single machine to a minimize total tardiness criterion.

S. O. Shim and Y. D. Kim (2007) optimized job scheduling on parallel identical machines by minimizing total tardiness criteria by means of the Branch and Bound algorithm (BAB). The determination of the upper limit uses metaheuristics namely Simulated Anealing (SA) algorithm, then the search using Depth First Search (DFS) strategy. The determination of the lower limit relies on several other studies. One research focuses on the one done by Y. K. Lin (2013). They showed that two lower bounds had been proposed to serve as a basis for comparison for large problems.

Another problem that is more complex is scheduling unrelated parallel machines. This problem has a higher level of complexity. The processing time of a job can be different for each machine. So, here comes the assignment problem to consider a shorter processing time when selecting the machine. The method developed for solving this problem is a heuristic method, metaheuristics, or enumeration. Kayvanfar et al. (2014) use a heuristic method to schedule using the Earliest Due Date (EDD), followed by calculating the deviation of each completion time and the due date of the job. It is used to choose the machine that will be used by the job. This method is repeated until the entire jobs are scheduled. Heuristic methods have the advantages of fast processing time. However, this method does not guarantee optimal results.

A heuristic methods will be developed and analyzed, in which its optimality is the development of priority dispatching method developed by A. Anggawijaya and V. Suhandi (2014). This method uses several criteria with a particular priority order. The results of this method will be compared with the enumeration method. The method is Generate and Test (G & T). G & T apply DFS search combined with Backtracking (BT). G & T method is only suitable for problems with a small number of jobs.

Optimality analysis has been done by comparing the results with a method that is able to provide optimal results. Y. K. Lin and C. W. Lin (2013) compare dispatching rule (heuristic) method using the Mixed Integer Linear Programming (MIP). They use the average deviation from the optimal value. There were no factors that consider the selection of cases, some cases are even easy to obtain good results and some cases are difficult to give a good performance measure. These factors serve as a reference point for assessing the zero point of the optimality closeness, where the optimal result is the highest point and represented by 100%. In this case, the optimal method is required to obtain the highest point. In addition, we use the First Come First Serve (FCFS) as the method for determining the zero point. FCFS method is used as a reference because of practicality. If the result from a method that has the same value with the result of FCFS method and different to the optimal performance, then the similarities to optimal or the optimality closeness is 0%. On other hand, when the result of a method that is close to optimal results and far away from the FCFS result, then the percentage is greater and gets closer to the optimum. This is what will be the performance measure of the method that is developed in this research.

One heuristic method that can be a reference is ATCR method. Y. K. Lin and C. W. Lin (2013) had developed this method that can solve unrelated parallel machines scheduling problem. This method use total weighted tardiness (TWT) as performance measure. Furthermore, this method has considered jobs release date that shows when jobs are ready to proceed. Herewith, we will compare the method which is developed here with this method. We may do some adjustment by using same weight for every jobs and time realize date are zero for all jobs. Here, we can treat TWT as total tardiness that is used in this research.

2. MATHEMATICAL FORMULATION

Mathematical formulation to minimize the total tardiness of job scheduling on unrelated parallel machines is a MIP problem with a combination of sequencing problems.

Notation:

Z total tardiness
t_i tardiness of job i
c_i completion time of job i
d_i due date of job i
s_i start time of job i
r_{jk} ready time of machine j when job with sequence number of k will be scheduled
p_{ij} processing time of job i on machine j
n total number of job
m total number of machine
u_k job at the sequence number of k on the schedule
x_{ij} state of job i be assigned on machine j
OC optimality closeness
w sample size or case to optimality closeness test
PD_v performance measure (total tardiness) by using PD method from sample number of v
$FCFS_v$ performance measure (total tardiness) by using FCFS method from sample number of v
GT_v performance measure (total tardiness) by using G & T method from sample number of v

Model

Decision Variable:

u_k

x_{ij}

Objective Function:

$$Min\ Z = \sum_{i=1}^{n} t_i \quad (1)$$

Constraint:

$$t_i = max(c_i - d_i, 0) \quad (2)$$

$$c_i = s_i + p_{ij} \quad (3)$$

$$x_{ij} = \begin{cases} 1, & \text{if job } i \text{ be scheduled on machine } j \\ 0, & \text{otherwise} \end{cases} \quad (4)$$

$$\sum_{j=1}^{m} x_{ij} = 1 \quad \text{for } i = 1..n \quad (5)$$

$$u_k \neq u_{k'} \quad \text{for } k, k' = 1..n \text{ where } k \neq k' \quad (6)$$

$$r_{jk} = \begin{cases} r_{jk-1} + p_{ij}, & \text{if } u_{k-1} = i \text{ and } x_{ij} = 1 \\ r_{jk-1}, & \text{otherwise} \end{cases} \quad \text{for } j = 1..m \quad (7)$$

$$s_i = r_{jk}, \quad \text{if } u_k = i \text{ and } x_{ij} = 1 \quad (8)$$

Formulation of Performance Measure of The Method:

$$OC = \frac{\sum_{v=1}^{w} \frac{PD_v - FCFS_v}{GT_v - FCFS_v}}{w} \qquad \text{where } GT_v \neq FCFS_v \qquad (9)$$

Asumption:

$r_{j1}=0$ for $j = 1..m$ shows the initial ready time of every machines equal to 0.

Description:

Equation (1) shows the objective function to minimize the total tardiness value which is the sum of the tardiness of each job. Each job tardiness value is obtained from the largest selection of the completion time minus the due date to zero. If not too late, the tardiness value is zero, as shown in Equation (2). Equation (3) shows the completion time equal to start time addition by job processing time. Equation (4) uses a binary value to declare a scheduled job on a machine. Equation (5) shows every job that can be selected only once to be scheduled, while implicitly, each machine may have more than one job. Inequality (6) gives the sequence number of k for the job and the job should not be assigned for another sequence number. Equation (7) is the equation to compute ready time machines. Its value can be different from the time of sequence number of k. Machines that have been assigned will have a different ready time with the earlier, which is added by processing time of the job scheduled to it while the previous time (k-1). The ready time of this machine will be a time to begin a new job with sequence number k, and scheduled in accordance with the machine. This is shown in Equation (8).

Equation (9) is used to analyze the optimality by assessing the optimality closeness. If the results of the FCFS method is are optimum, it is stated that this case is not included in assessing the optimality closeness.

3. PRIORITY DISPATCHING (PD) METHOD

The development of priority dispatching method for scheduling jobs on unrelated parallel machines has been conducted by many researchers, A. Anggawijaya and V. Suhandi have developed this method with four criteria. The criteria are tardiness, engine load, ready time and the due date. However, the optimality analysis of the method has not been done. The method that would be developed contain phased scheduling algorithm with reference to the priorities determined, based on five criteria and the optimality that would be tested.

These criteria based on the priorities are listed as follows:

1. Schedule the job by looking at the value of the smallest tardiness of each job when scheduled on a machine and tardiness is not equal to zero.
2. Select the pair of a job and a machine when the job is scheduled on the machines will have a minimum number of options that are not too late.
3. Select the machine with the smallest ready time.
4. Choose the machine with the smallest and greater than zero of Σp_{ij}. The Σp_{ij} is the total time for all the jobs that have not been scheduled on each machine.
5. Choose a job with the smallest due date.

The first criterion is very important in choosing a job that is definitely too late, then the selection of the value of the smallest tardiness becomes the first choice. Secondly, it requires a job which has few machine options that are not too late when the job is scheduled for it, it will be prioritized immediately. The third criterion, choose the machine with the smallest ready time machine. This is done when there is a condition with more than one pair of job and a machine in the list of second criterion. Fourth criterion performs load balancing of each machine. The machine that is only capable of doing a particular job would be prioritized, so that the machine with highly variation of capability will get another job. If the load value is zero, it means there is no job that can be assigned to the machine. The last criterion is applied to select the job after the third and fourth generates more than one pair of jobs and machines. Flowchart PD method is described in detail in Figure 1.

Figure 1 shows the process of the selection of job and machine in stages until the entire job is successfully scheduled. This process is done by screening the pairs (job and machine) who meet the filter criteria. The first criterion generates list A, the second criterion generates list B, and so on until the last criterion generates list E.

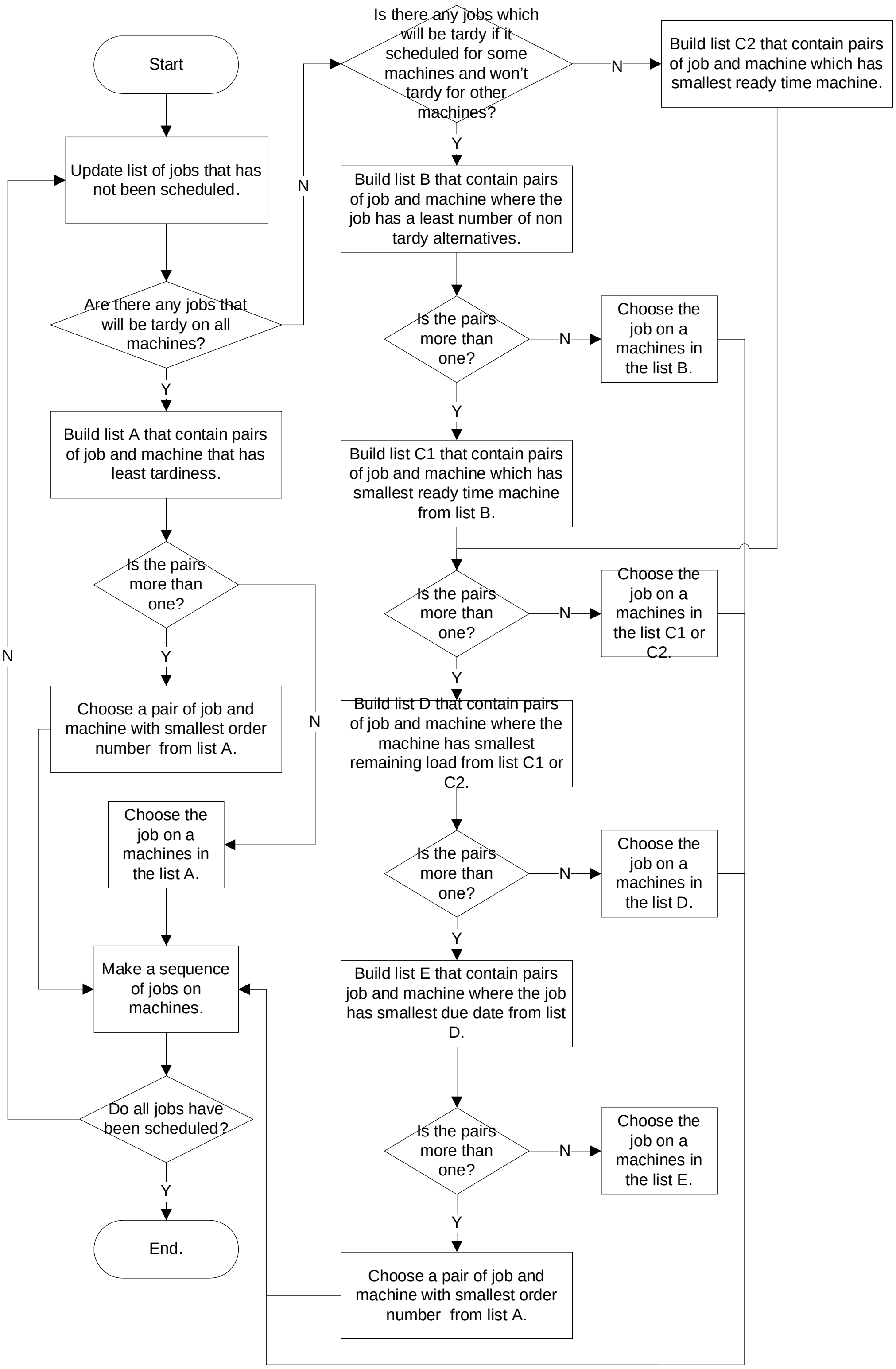


Figure 1. Priority Dispatching (PD) flowchart

Case 1 in Table 1 represents a job scheduling problems on unrelated parallel machines. There is a department that has three machines, and at one time there were six jobs on queuing.

Each job requires a single process. The process can be performed in a single machine or choose one of several machines. The processing time can be seen in Table 1.

At the first stage, no job has been able to generate tardiness, as seen lower part of Table 1. In this case, the list A and B is not generated. List C2 that contains the pair of job and machine that has the smallest ready time (0). The result is the entire pair (18 pairs) on list C2. Further pairs are filtered by selecting machines that have the lowest load (122). There are 6 pairs on list D. Then list E contains a pair for the smallest due date (40), so that the selected pair is job 1 on machine 3. The lists for every stage can be viewed in Table 4.

At the second stage, similar to the first stage but on list E there are 4 pairs, so that the selected pair is the pair with the smallest job order number and smallest machine number.

At the third stage, there are 3 jobs (3, 5, 6) which are possible to be tardy, but there are opportunities for the job not to be tardy if they are assigned to a particular machine, so that list B contains 6 pairs to be an alternative for those who are not tardy (on machine 2 and machine 3). Furthermore, the pairs are filtered based on the smallest machine ready time. We obtain 3 couples on list C1. Altogether, these happens to be on the machine 2. Three pairs continue to fill list D. Furthermore, Job 3 is the only one in list E due to the smallest due date. So, at this stage it is better to choose job 3 on machine 2.

Table 1. Case 1 on stage 1 and stage 2

Stage 1				
Job	M 1	M 2	M 3	Due date
1	12	15	10	40
2	23	21	22	42
3	21	25	26	42
4	18	20	15	44
5	23	19	21	45
6	31	31	28	46
Computation				
Job	M 1	M 2	M 3	Due date
r_{jk}	0	0	0	
Σp_{ij}	128	131	122	
1	0	0	0	40
2	0	0	0	42
3	0	0	0	42
4	0	0	0	44
5	0	0	0	45
6	0	0	0	46
assign job 1 on machine 3				

Stage 2				
Job	M 1	M 2	M 3	Due date
2	23	21	22	42
3	21	25	26	42
4	18	20	15	44
5	23	19	21	45
6	31	31	28	46
Computation				
Job	M 1	M 2	M 3	Due date
r_{jk}	0	0	10	
Σp_{ij}	116	116	112	
2	0	0	0	42
3	0	0	0	42
4	0	0	0	44
5	0	0	0	45
6	0	0	0	46
assign job 2 on machine 1				

Table 2. Case 1 on stage 3 and stage 4

Stage 3				
Job	M 1	M 2	M 3	Due date
3	21	25	26	42
4	18	20	15	44
5	23	19	21	45
6	31	31	28	46
Computation				
Job	M 1	M 2	M 3	Due date
r_{jk}	23	0	10	
Σp_{ij}	93	95	90	
3	2	0	0	42
4	0	0	0	44
5	1	0	0	45
6	8	0	0	46
assign job 3 on machine 2				

Stage 4				
Job	M 1	M 2	M 3	Due date
4	18	20	15	44
5	23	19	21	45
6	31	31	28	46
Computation				
Job	M 1	M 2	M 3	Due date
r_{jk}	23	25	10	
Σp_{ij}	72	70	64	
4	0	1	0	44
5	1	0	0	45
6	8	10	0	46
assign job 6 on machine 3				

At the fourth stage there is only 1 pair in list B; job 6 has only one alternative for not to be tardy. It can be assigned to the machine 3 that is not tardy. Instead of this, the other couples still have a lot more alternatives.

At the fifth stage, list B has 2 pairs, one is job 4 on machine 1 and the other is job 5 on machine 2. Next, list C1 contains machine 1 with the smallest ready time, so that the selected pair is job 4 on machine 1.

At the last stage, the job 5 on the machine 2 is the pair which is selected on list B.

Table 3. Case 1 on stage 5 and stage 6

Stage 5				
Job	M 1	M 2	M 3	Due date
4	18	20	15	44
5	23	19	21	45
Computation				
Job	M 1	M 2	M 3	Due date
r_{jk}	23	25	38	
Σp_{ji}	41	39	36	
4	0	1	9	44
5	1	0	14	45
assign job 4 on machine 1				

Stage 6				
Job	M 1	M 2	M 3	Due date
5	23	19	21	45
Computation				
Job	M 1	M 2	M 3	Due date
r_{jk}	41	25	38	
Σp_{ji}	23	19	21	
5	19	0	14	45
assign job 5 on machine 2				

Table 4. Jobs and Machines Lists for every Stage

Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6
List C2	List C2	List B	List B	List B	List B
Job 1 - M1	Job 2 - M1	Job 3 - M2	Job 6 - M3	Job 4 - M1	Job 5 - M2
Job 1 - M2	Job 2 - M2	Job 3 - M3		Job 5 - M2	
Job 1 - M3	Job 3 - M1	Job 5 - M2		List C1	
Job 2 - M1	Job 3 - M2	Job 5 - M3		Job 4 - M1	
...	...	Job 6 - M2			
Job 6 - M3	Job 6 - M2	Job 6 - M3			
List D	List D	List C1			
Job 1 - M3	Job 2 - M1	Job 3 - M2			
Job 2 - M3	Job 2 - M2	Job 5 - M2			
Job 3 - M3	Job 3 - M1	Job 6 - M2			
Job 4 - M3	Job 3 - M2	List D			
Job 5 - M3	...	Job 3 - M2			
Job 6 - M3	Job 6 - M2	Job 5 - M2			
List E	List E	Job 6 - M2			
Job 1 - M3	Job 2 - M1	List E			
	Job 2 - M2	Job 3 - M2			
	Job 3 - M1				
	Job 3 - M2				

Table 5. Job sequence on machines for Case 1 using PD method

	Job Sequence		
	1	2	3
M 1	2	4	
M 2	3	5	
M 3	1	6	

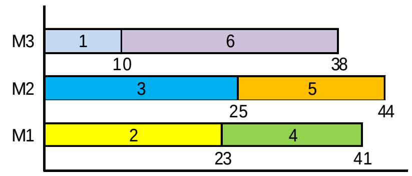


Figure 2. Gantt Chart for Case 1 using Priority Dispatching (PD) method

Table 5 shows the sequence of jobs on each machine. Furthermore, Figure 2 shows the completion time for each job. When we compare it with the due date, there are no tardy jobs. Thus, the total tardiness is zero.

4. FIRST COME FIRST SERVE (FCFS) METHOD

FCFS scheduling method is a simple method by means of assigning jobs which come first according to the time of issuance of the order and done in advance by selecting the machine with the smallest ready time. This method is widely used because of its practicality but this method is usually far from optimal because of the lack of consideration of the factors that affect the size of the desired performance.

Due to the practicality, the result of the FCFS method can be used as a reference as the zero point on optimality closeness assessment. Expectedly, the result of an evaluated method must be better than the results obtained from this method.

Result FCFS method is shown in Figure 3. The total tardiness produced by 8 units of time. This result was obtained by comparing the completion time of each job with the due date listed in Table 1.

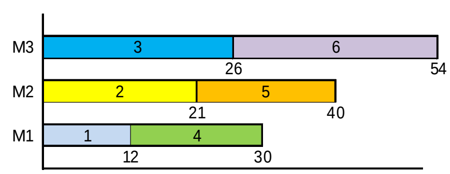
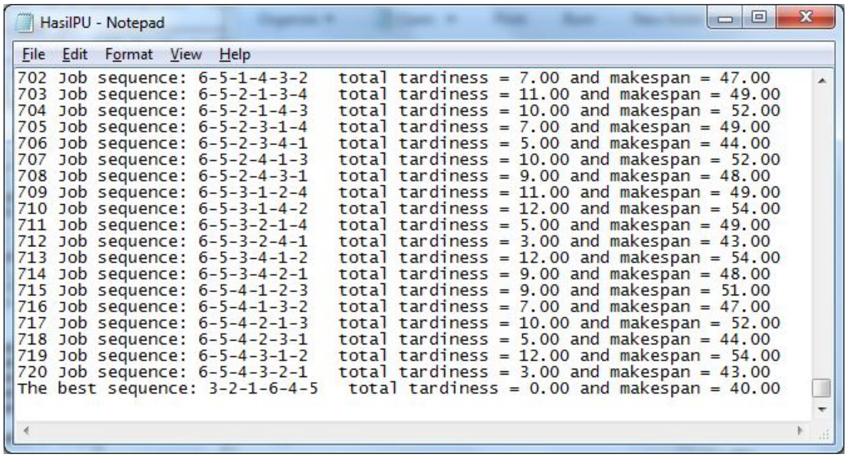


Figure 3. Gantt Chart for Case 1 using FCFS method

5. GENERATE & TEST (G & T) METHOD

G & T method is a method of enumeration with depth first search (DFS) strategies combined with backtracking. Detailed algorithms are developed from the research of V. Suhandi and M. S. Ismanto (2013), which has previously developed the G & T algorithm for scheduling jobs on identical parallel machines. Development is done to accommodate the processing time variation that existed in the unrelated parallel machines scheduling problem.



```
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702 Job sequence: 6-5-1-4-3-2   total tardiness = 7.00 and makespan = 47.00
703 Job sequence: 6-5-2-1-3-4   total tardiness = 11.00 and makespan = 49.00
704 Job sequence: 6-5-2-1-4-3   total tardiness = 10.00 and makespan = 52.00
705 Job sequence: 6-5-2-3-1-4   total tardiness = 7.00 and makespan = 49.00
706 Job sequence: 6-5-2-3-4-1   total tardiness = 5.00 and makespan = 44.00
707 Job sequence: 6-5-2-4-1-3   total tardiness = 10.00 and makespan = 52.00
708 Job sequence: 6-5-2-4-3-1   total tardiness = 9.00 and makespan = 48.00
709 Job sequence: 6-5-3-1-2-4   total tardiness = 11.00 and makespan = 49.00
710 Job sequence: 6-5-3-1-4-2   total tardiness = 12.00 and makespan = 54.00
711 Job sequence: 6-5-3-2-1-4   total tardiness = 5.00 and makespan = 49.00
712 Job sequence: 6-5-3-2-4-1   total tardiness = 3.00 and makespan = 43.00
713 Job sequence: 6-5-3-4-1-2   total tardiness = 12.00 and makespan = 54.00
714 Job sequence: 6-5-3-4-2-1   total tardiness = 9.00 and makespan = 48.00
715 Job sequence: 6-5-4-1-2-3   total tardiness = 9.00 and makespan = 51.00
716 Job sequence: 6-5-4-1-3-2   total tardiness = 7.00 and makespan = 47.00
717 Job sequence: 6-5-4-2-1-3   total tardiness = 10.00 and makespan = 52.00
718 Job sequence: 6-5-4-2-3-1   total tardiness = 5.00 and makespan = 44.00
719 Job sequence: 6-5-4-3-1-2   total tardiness = 12.00 and makespan = 54.00
720 Job sequence: 6-5-4-3-2-1   total tardiness = 3.00 and makespan = 43.00
The best sequence: 3-2-1-6-4-5   total tardiness = 0.00 and makespan = 40.00
```

Figure 4. The result for Case 1 using G & T method

A problem with 6 jobs and 3 machines will produce 6! combinations of sequence. There are 720 sequences, shown in Figure 4. The results indicated a sequence of jobs that will be processed. The sequence is job 3, 2, 1, 6, 4, and 5. The Jobs are assigned by choosing the machine with the smallest ready time. The job assignment on each machines are shown in Table 6. The Tardiness is calculated by comparing the completion time of each job by the due date of each job listed in Table 1. Figure 5 shows the Gantt chart to make it more easily understood. The results obtained guaranteed the optimality. In this case, it is the smallest total tardiness and the result is zero.

Table 6. Job sequence on machines for Case 1 using G & T method

	Job Sequence		
	1	2	3
M 1	3	4	
M 2	2	5	
M 3	1	6	

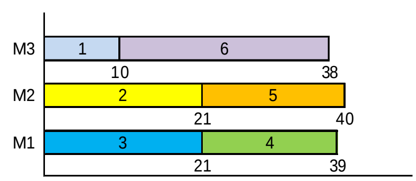

Figure 5. Gantt Chart for Case 1 using G & T method

6. Apparent Tardiness Cost with Release Date (ATCR) Method

Y. K. Lin and C. W. Lin (2013) had introduced ATCR method with some others methods. ATCR method is the only one which dealing with tardiness. They use total weighted tardiness (TWT) as performance measure. This method is much closer to PD method, which use total tardiness as performance measure. We can use weight equal to one that lead TWT same as total tardiness, then we can compare them both. Furthermore, the characteristics of these methods are heuristics. They seek a good solution by using an algorithm which is not time consuming when solving large problem.

The problem adjusted by added jobs weight and release date, it is shown in Table 7. Dispatching rule ATCR for the case step by step is shown in Table 8. The results are machine 1 do job 3 and job 4, machine 2 do job 2 and job 5, and machine 3 do job 6 and job 1. TWT or total tardiness is zero.

Table 7. Processing time matrix

	j1	j2	j3	j4	j5	j6
m1	12	23	21	18	23	31
m2	15	21	25	20	19	31
m3	10	22	26	15	21	28
wj	1	1	1	1	1	1
rj	0	0	0	0	0	0
dj	40	42	42	44	45	46

7. OPTIMALITY CLOSENESS (OC)

Case 1 was solved previously by using the method of PD, FCFS, and G & T. The result is PD method gets the optimum solution with zero total tardiness. These results are similar to those produced by G & T method. As for the FCFS method there is total tardiness of 8 units of time. We cannot conclude that PD has a good result because we use only a single case to be used as a reference.

Table 8. Job sequence on machines for Case 1 using G & T method

	Step 1		Step 2	Step 3						Step 4				Step 5 - 6		weighted	Step 7
Iter	U	pi* bar	i*	Ii*1	Ii*2	Ii*3	Ii*4	Ii*5	Ii*6	C1j*	C2j*	C3j*	i**	Schedule	ti**	tardiness	API
1	{1,2,3,4,5,6}	21.33333	1	0.00012	0.00051	0.00035	0.00013	0.00025	0.00096	31	31	28	3	m1:	0		
														m2:	0		
														m3:6	28	0	
2	{1,2,3,4,5}	19.4	1	0.00006	0.00032	0.00021	0.00007	0.00015	-	23	21	50	2	m1:	0		
														m2:2	21	0	
														m3:6	28		
3	{1,3,4,5}	18.5	1	0.00004	-	0.00016	0.00005	0.00011	-	21	46	54	1	m1:3	21	0	
														m2:2	21		
														m3:6	28		
4	{1,4,5}	17.66667	1	0.01149	-	-	0.01349	0.03276	-	44	40	49	1	m1:3	21		
														m2:2,5	40	0	
														m3:6	28		
5	{1,4}	15	1	0.00808	-	-	0.01049	-	-	39	60	43	1	m1:3,4	39	0	
														m2:2,5	40		
														m3:6	28		
6	{1}	10	3	0.10000	-	-	-	-	-	51	55	38	3	m1:3,4	39		
														m2:2,5	40		
														m3:6,1	38	0	
															TOTAL	0	0

Therefore, it is necessary to develop other hypothetical cases to be more convincing. Generation of processing time and due date of each job on each machine using random numbers is one solution. Job processing time varies in each machine using the Uniform distribution (15, 25). While the due date uses the Uniform distribution (30, 50). Cases with 6 jobs and 3 machines will produce an average of assignment 2 jobs on each machine, so that the due date is used around 2 times the processing time of each job in a machine. Variations generated by the uniform distribution would be a possible occurrence of tardiness. The sample size is 10 cases in order to obtain the value of OC (optimality closeness). The cases are shown in Table 9.

The results obtained are shown in Table 10. PD method got the OC value of 91.75%. This shows that the PD method gives good results because it is close to the optimum. ATCR method shows better result with OC value of 92.97%. The results show that ATCR method is superior than PD method.

There are three times that ATCR method got better result than PD method (case 1, 2, and 7). At the other side, only two times that PD method got better result than ATCR method (case 5 and 10). However ATCR method had better results in average, PD method still have a better result in some cases. We can use PD method redundantly with ATCR method due to easiness of heuristics method.

Experiments to test the PD method are also developed in cases where not all machines are able to do all the jobs. Uniform distributed random numbers (0, 3) is used to determine which machine can do a job. If the number 0 appears then the job can be done on all machines. If the number 1 appears, then machine 1 cannot do the job, and so on up to machines 3.

The resulting value of OC is 50.42%. It shows there are still many weaknesses of the PD method to be applied in cases where not all work can be done on all machines. OC calculation for this case can be seen in Table 11. ATCR method can deliver good result with OC value by 75.11%. Same with first experiment category, PD method had inferior results than ATCR method but still have good results in some cases and better than results from ATCR method.

7. CONCLUSION

Development of PD method has considered a lot of factors which affect to the total tardiness. The first criterion affects directly to the total tardiness. The second criterion indicates that there is an effort to select no to be tardy if there are some alternatives. The third criterion considers the ready time machine to balance the current load. It is indirectly influences the tardiness. The fourth criterion is needed to seek future balance on each machine when there is a difference in the processing time. This is because each machine may have a different process for doing the same job. The fifth criterion is a due date that is a time when a job is declared to be tardy.

Table 9. Ten cases for all machines that can do all jobs and ten cases for category that not all machine can do all jobs

Case 1

Job	M1	M2	M3	Due
1	20	17	24	45
2	23	16	23	31
3	22	23	22	46
4	19	16	18	31
5	24	24	16	30
6	25	23	23	32

Case 2

Job	M1	M2	M3	Due
1	25	20	15	30
2	23	22	20	42
3	23	20	24	41
4	17	22	22	45
5	22	20	23	38
6	22	19	23	33

Case 3

Job	M1	M2	M3	Due
1	23	21	16	31
2	22	19	20	42
3	17	22	16	38
4	18	22	16	45
5	20	25	25	40
6	18	24	20	38

Case 4

Job	M1	M2	M3	Due
1	23	18	18	50
2	17	24	24	36
3	23	22	15	38
4	15	22	15	47
5	17	21	21	46
6	19	15	18	31

Case 5

Job	M1	M2	M3	Due
1	17	22	15	37
2	19	21	17	35
3	20	22	21	36
4	25	17	19	50
5	24	20	25	47
6	17	15	20	34

Case 6

Job	M1	M2	M3	Due
1	18	22	21	48
2	19	25	22	43
3	17	21	15	36
4	17	21	23	44
5	24	23	21	42
6	22	23	20	39

Case 7

Job	M1	M2	M3	Due
1	24	20	17	41
2	21	15	24	44
3	15	20	21	49
4	21	20	16	41
5	17	16	18	33
6	24	18	15	34

Case 8

Job	M1	M2	M3	Due
1	24	25	24	36
2	24	15	18	36
3	18	18	20	49
4	20	20	24	45
5	22	17	21	30
6	17	17	21	50

Case 9

Job	M1	M2	M3	Due
1	17	17	17	37
2	17	22	22	40
3	19	20	25	43
4	17	21	18	33
5	22	19	25	43
6	19	21	16	35

Case 10

Job	M1	M2	M3	Due
1	18	18	23	40
2	24	25	25	37
3	17	24	18	37
4	25	25	21	34
5	18	15	24	33
6	21	21	23	40

Case 1

Job	M1	M2	M3	Due
1	20	17	-	45
2	-	16	23	31
3	22	23	22	46
4	19	16	-	31
5	-	24	16	30
6	25	23	-	32

Case 2

Job	M1	M2	M3	Due
1	-	20	15	30
2	23	22	20	42
3	23	20	24	41
4	-	22	22	45
5	-	20	23	38
6	-	19	23	33

Case 3

Job	M1	M2	M3	Due
1	23	21	-	31
2	22	19	20	42
3	17	22	-	38
4	18	-	16	45
5	20	25	25	40
6	18	-	20	38

Case 4

Job	M1	M2	M3	Due
1	-	18	18	50
2	17	-	24	36
3	23	22	15	38
4	-	22	15	47
5	17	-	21	46
6	19	15	-	31

Case 5

Job	M1	M2	M3	Due
1	17	22	15	37
2	-	21	17	35
3	20	-	21	36
4	-	17	19	50
5	24	20	-	47
6	17	15	20	34

Case 6

Job	M1	M2	M3	Due
1	-	22	21	48
2	19	-	22	43
3	17	21	-	36
4	17	21	23	44
5	24	23	-	42
6	22	-	20	39

Case 7

Job	M1	M2	M3	Due
1	-	20	17	41
2	-	15	24	44
3	15	-	21	49
4	21	-	16	41
5	17	16	18	33
6	24	18	-	34

Case 8

Job	M1	M2	M3	Due
1	-	25	24	36
2	24	15	18	36
3	18	-	20	49
4	20	-	24	45
5	-	17	21	30
6	17	-	21	50

Case 9

Job	M1	M2	M3	Due
1	17	17	-	37
2	-	22	22	40
3	-	20	25	43
4	17	21	18	33
5	-	19	25	43
6	19	21	16	35

Case 10

Job	M1	M2	M3	Due
1	18	18	-	40
2	24	25	25	37
3	-	24	18	37
4	25	25	21	34
5	18	15	24	33
6	21	21	23	40

Table 10. OC computation for cases where all machines can process all the jobs

Case	Total Tardiness FCFS	G&T	PD	ATCR	FCFS-G&T	FCFS-PD	FCFS-ATCR	PD Optimality Closeness (%)	ATCR Optimality Closeness (%)
1	28	1	9	3	27	19	25	70.37	92.59
2	23	0	1	0	23	22	23	95.65	100
3	7	0	2	2	7	5	5	71.43	71.43
4	8	0	0	0	8	8	8	100	100
5	7	0	0	1	7	7	6	100	85.71
6	9	0	0	0	9	9	9	100	100
7	20	0	1	0	20	19	20	95	100
8	11	0	0	0	11	11	11	100	100
9	7	0	0	0	7	7	7	100	100
10	24	4	7	8	20	17	16	85	80
							OC	91.75	92.97

Table 11. OC computation for cases where any machines cannot process all the jobs

Case	Total Tardiness FCFS	G&T	PD	ATCR	FCFS-G&T	FCFS-PD	FCFS-ATCR	PD Optimality Closeness (%)	ATCR Optimality Closeness (%)
1	22	1	7	1	21	15	21	71.43	100
2	37	4	29	32	33	8	5	24.24	15.15
3	7	0	13	5	7	-6	2	-85.71	28.57
4	2	0	0	0	2	2	2	100	100
5	7	0	0	1	7	7	6	100	85.71
6	7	0	0	0	7	7	7	100	100
7	29	0	0	0	29	29	29	100	100
8	12	0	0	4	12	12	8	100	66.67
9	7	0	13	0	7	-6	7	-85.71	100
10	24	4	8	13	20	16	11	80	55
							OC	50.42	75.11

PD method which is developed can gain the value of OC by 91.75% for the case of the whole machine that can do the whole job. These results show closeness to optimal results. The main advantage of PD method is the ability to solve very large problems. This is a constraint in G & T method which is able to provide optimum results but only able to solve the maximum number of 15 jobs. Computing time is worth to considering. Furthermore, it is influenced by the development of computer hardware in calculating the speed.

In the case that not all machines are able to do all the jobs, the OC values obtained at 50.42%. This shows there are still many things that can be improved related to the priority dispatching method. Another study is expected to be a breakthrough to face such problems.

Comparing PD method to ATCR method that had developed before by Y. K. Lin and C. W. Lin (2013), PD method are inferior than ATCR method by 1.22% for cases that all jobs can be done in all machines and 24.69% for cases that some jobs cannot be done in all machines. Even though PD method is inferior but still had better results for some cases. PD method may be alternative method beside ATCR method to solve unrelated parallel machine scheduling problem situation.

The use of OC values that has been considered to be the zero point is expected to assess the performance of a method in a more critical way. Thus, it is helpful to exclude too easy cases when FCFS method was able to provide optimal results.

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